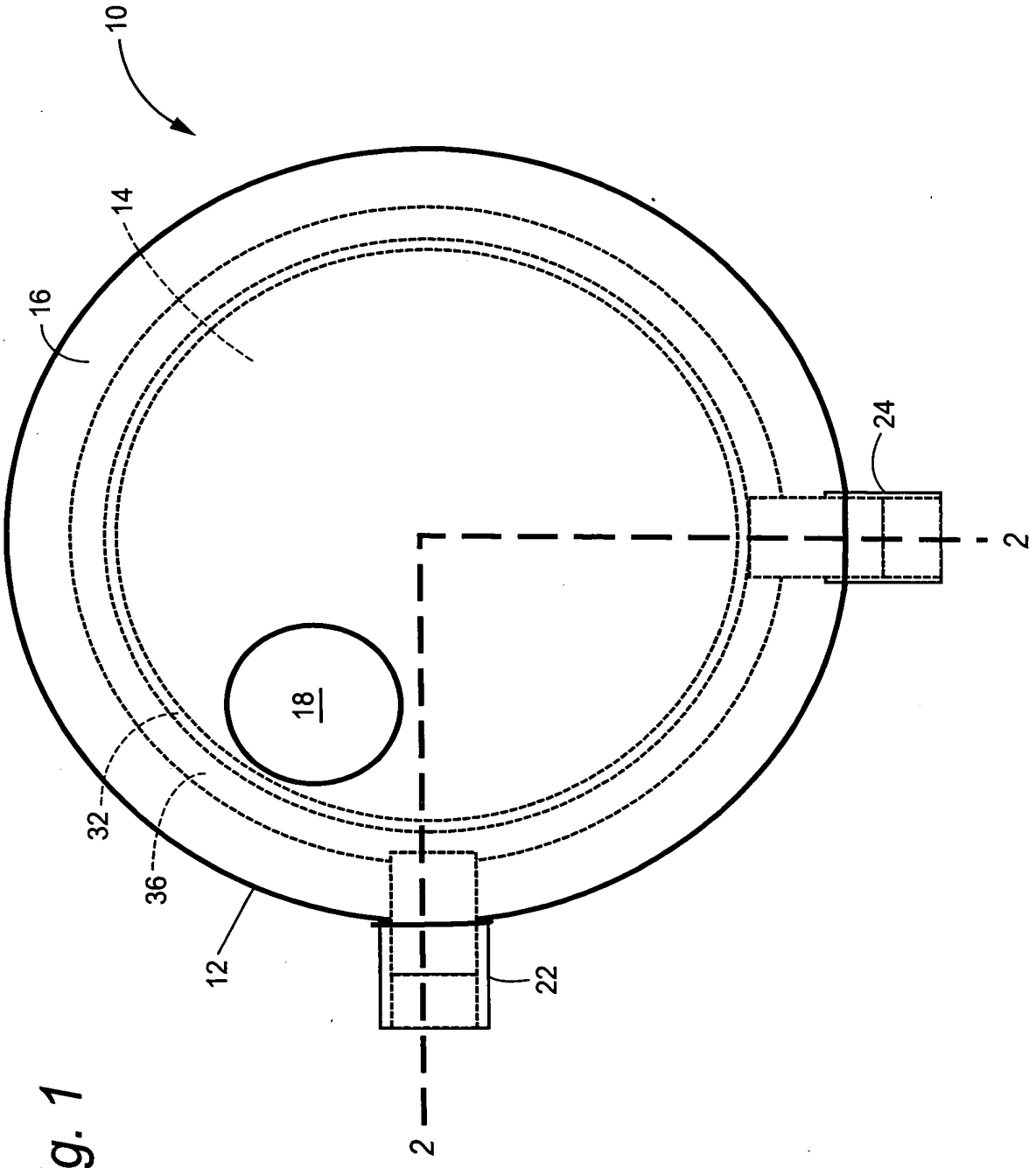


Fig. 1

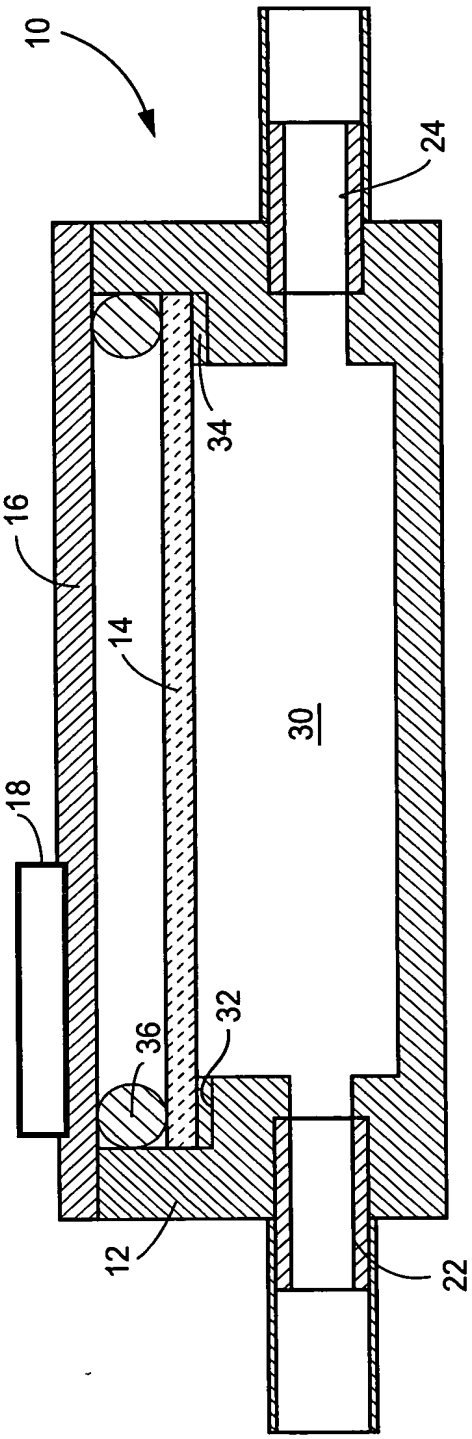


Fig. 2

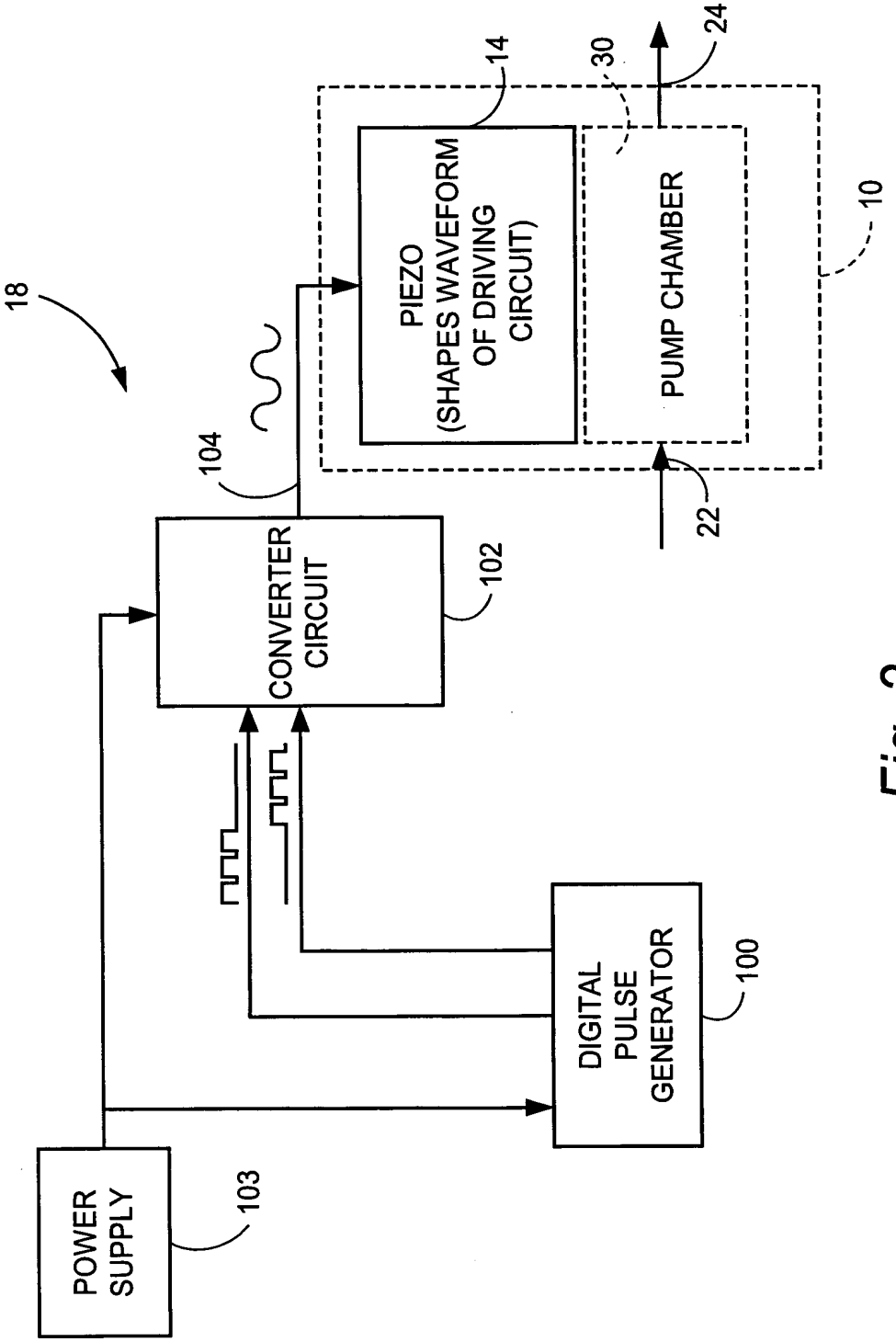

18
POWER SUPPLY
103
DIGITAL PULSE GENERATOR
100
CONVERTER CIRCUIT
102
104
PIEZO (SHAPES WAVEFORM OF DRIVING CIRCUIT)
14
PUMP CHAMBER
30
10
22
24

Fig. 3

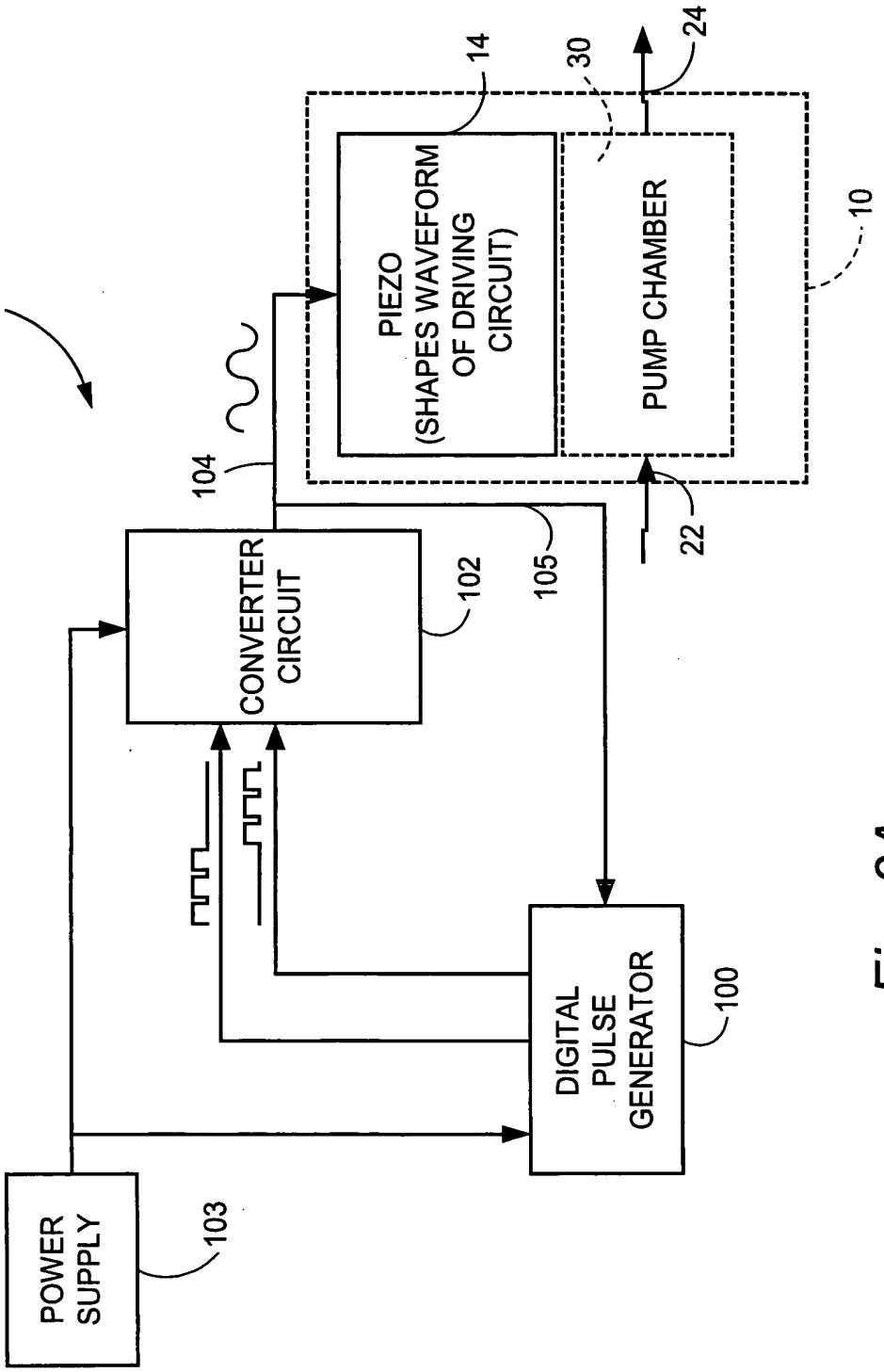

18A
POWER SUPPLY
103
CONVERTER CIRCUIT
102
DIGITAL PULSE GENERATOR
100
104
105
PIEZO (SHAPES WAVEFORM OF DRIVING CIRCUIT)
14
PUMP CHAMBER
30
10
22
24

Fig. 3A

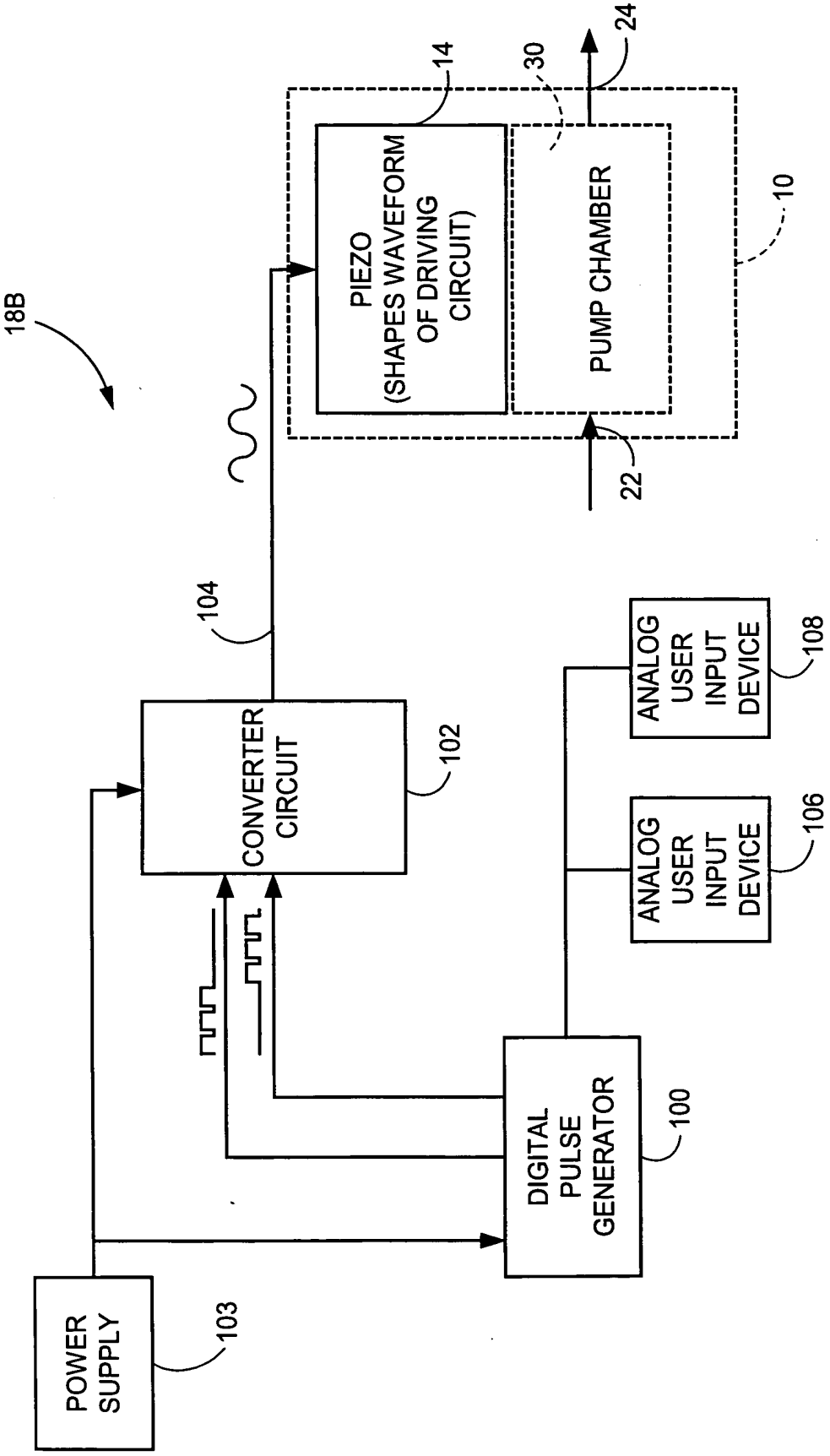

18B
POWER SUPPLY
103
CONVERTER CIRCUIT
102
104
DIGITAL PULSE GENERATOR
100
ANALOG USER INPUT DEVICE
106
ANALOG USER INPUT DEVICE
108
PIEZO (SHAPES WAVEFORM OF DRIVING CIRCUIT)
14
PUMP CHAMBER
30
10
22
24

Fig. 3B

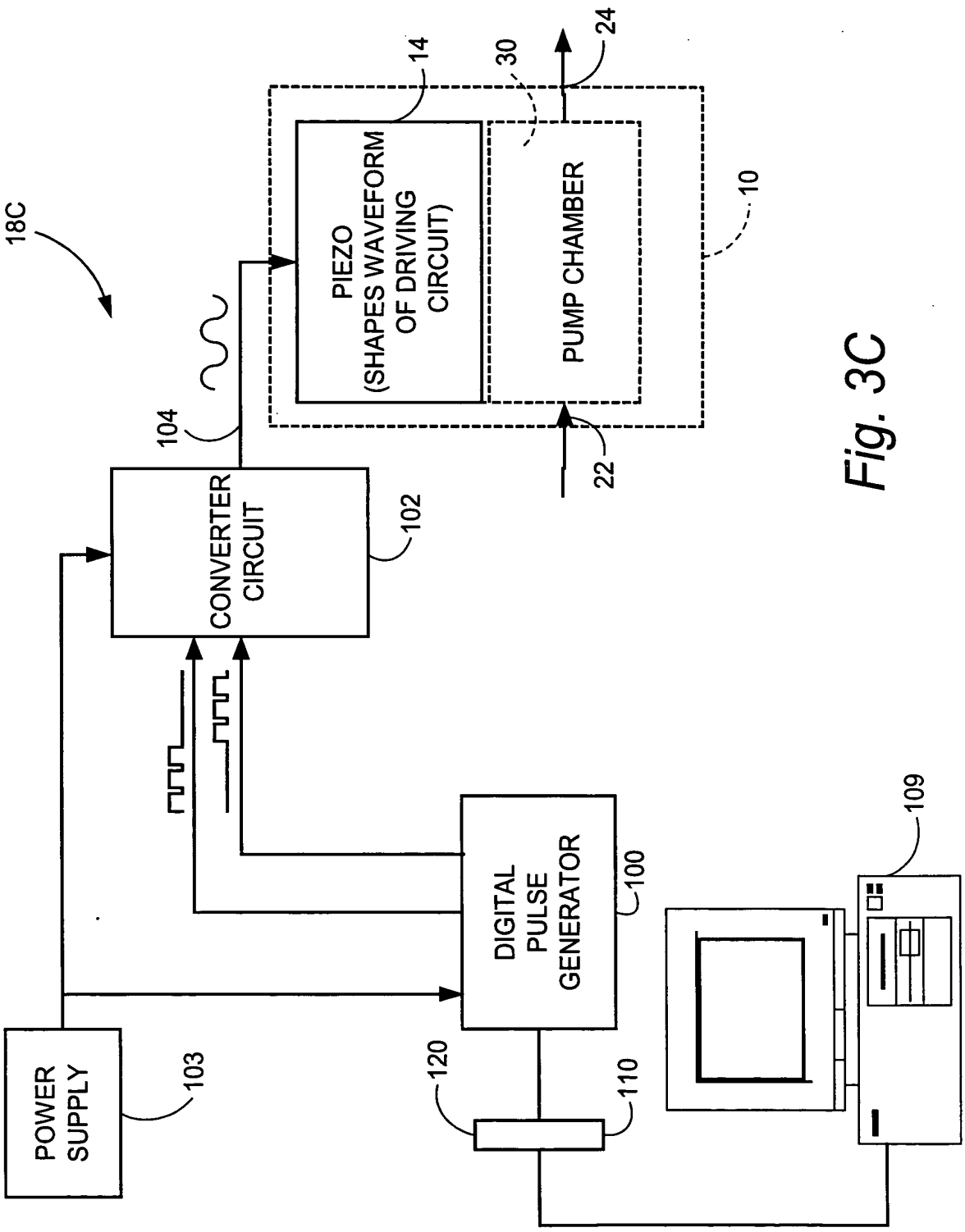

18C
POWER SUPPLY
103
CONVERTER CIRCUIT
102
104
PIEZO (SHAPES WAVEFORM OF DRIVING CIRCUIT)
14
PUMP CHAMBER
30
24
22
10
DIGITAL PULSE GENERATOR
100
120
110
109

Fig. 3C

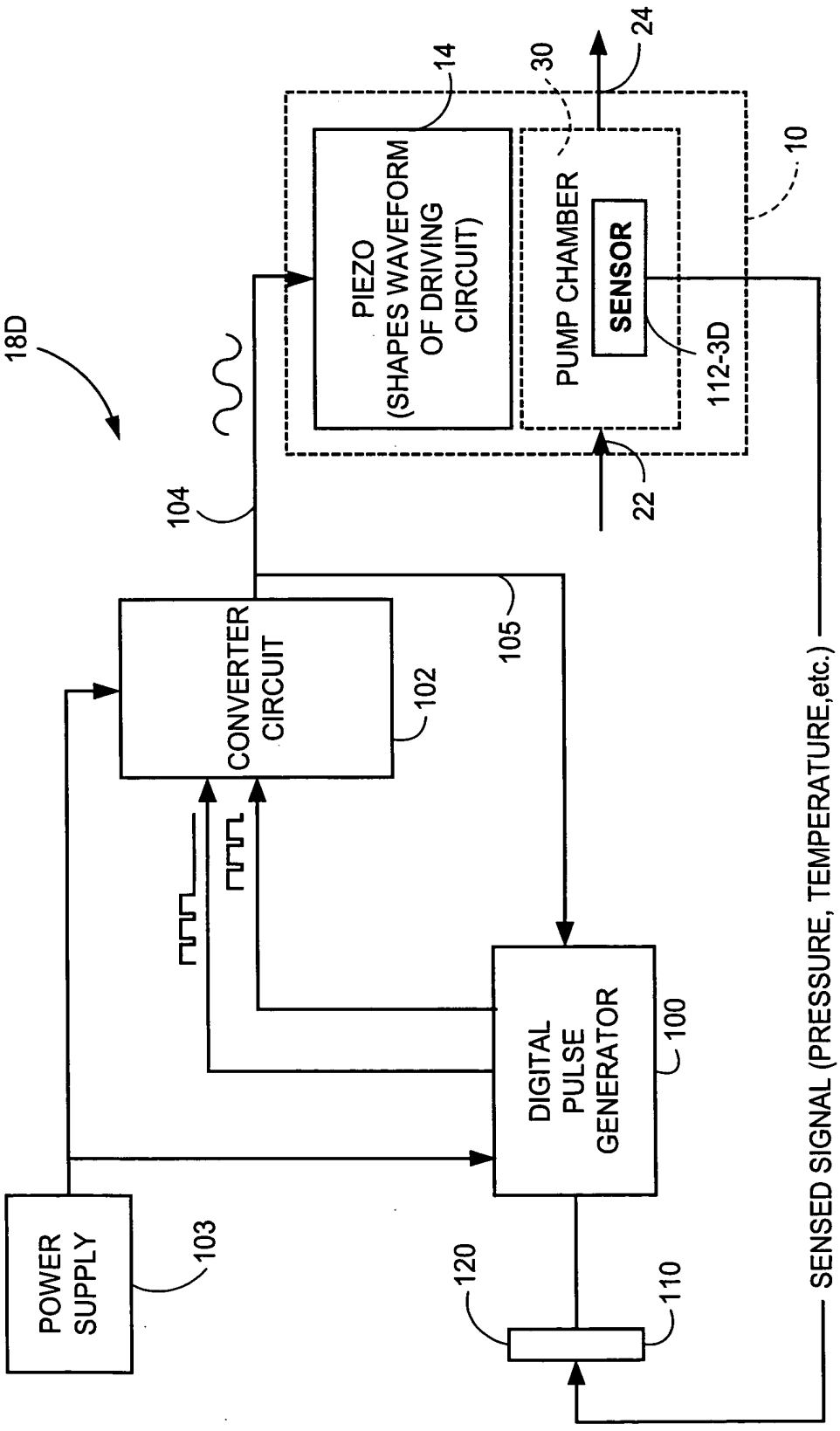

18D
PIEZO
(SHAPES WAVEFORM
OF DRIVING
CIRCUIT)
14
30
24
PUMP CHAMBER
SENSOR
112-3D
10
22
104
105
CONVERTER
CIRCUIT
102
DIGITAL
PULSE
GENERATOR
100
POWER
SUPPLY
103
120
110
SENSED SIGNAL (PRESSURE, TEMPERATURE,etc.)

Fig. 3D

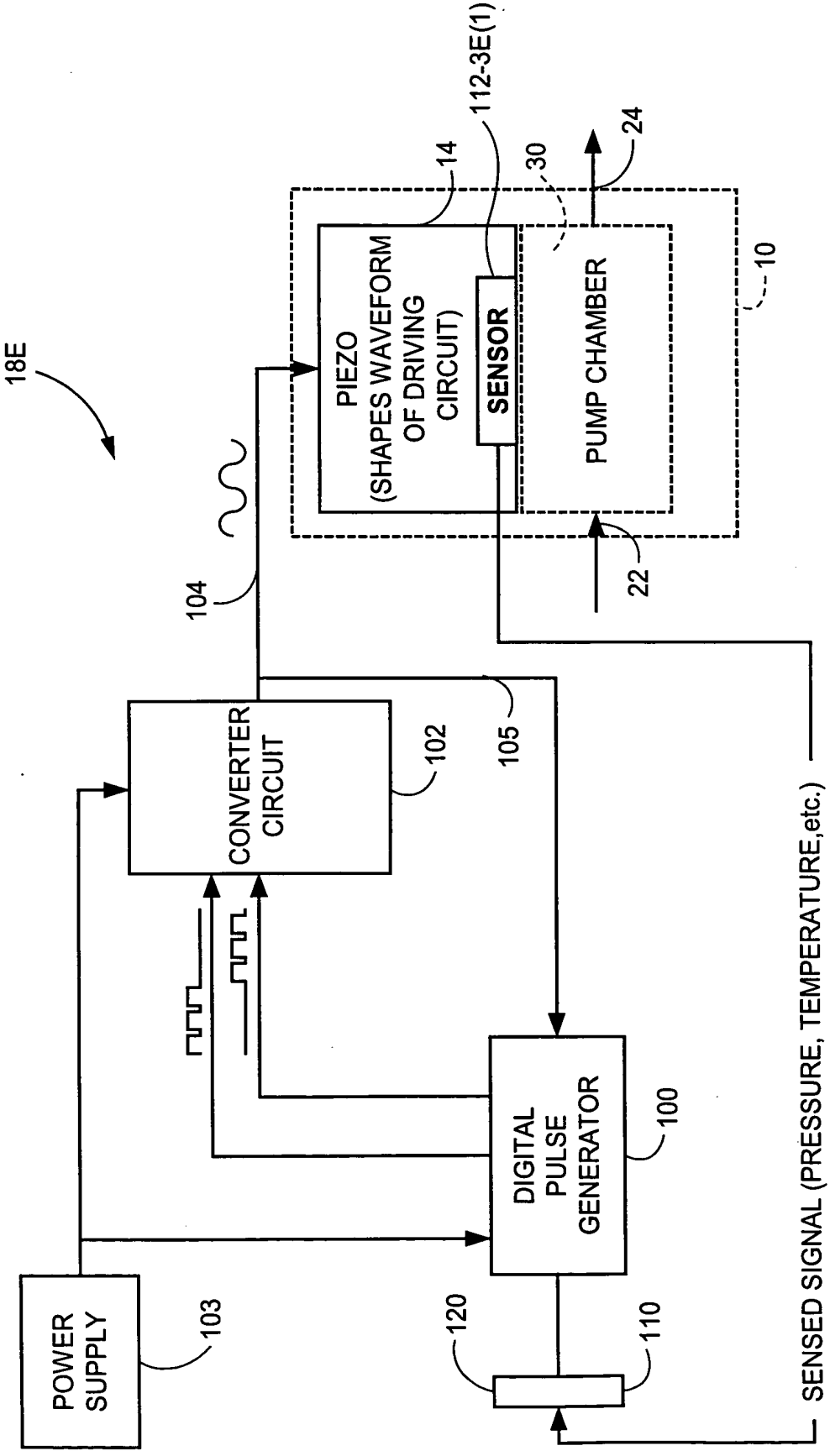

18E
POWER SUPPLY
103
CONVERTER CIRCUIT
102
DIGITAL PULSE GENERATOR
100
104
105
120
110
PIEZO (SHAPES WAVEFORM OF DRIVING CIRCUIT)
SENSOR
PUMP CHAMBER
14
112-3E(1)
30
24
22
10
SENSED SIGNAL (PRESSURE, TEMPERATURE,etc.)

Fig. 3E(1)

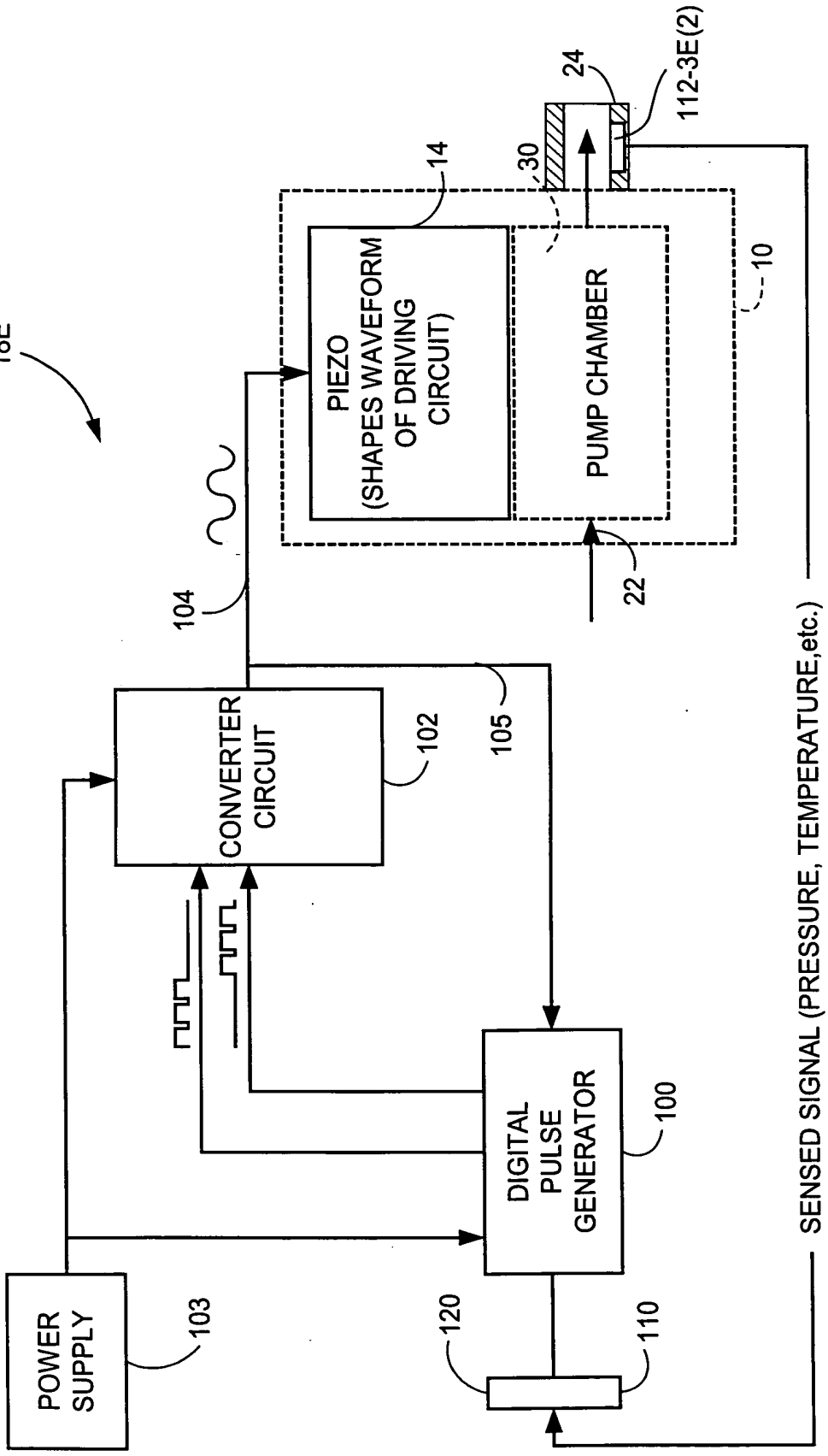

18E
POWER SUPPLY
103
CONVERTER CIRCUIT
102
104
105
PIEZO (SHAPES WAVEFORM OF DRIVING CIRCUIT)
14
PUMP CHAMBER
10
30
24
112-3E(2)
22
DIGITAL PULSE GENERATOR
100
120
110
SENSED SIGNAL (PRESSURE, TEMPERATURE,etc.)

Fig. 3E(2)

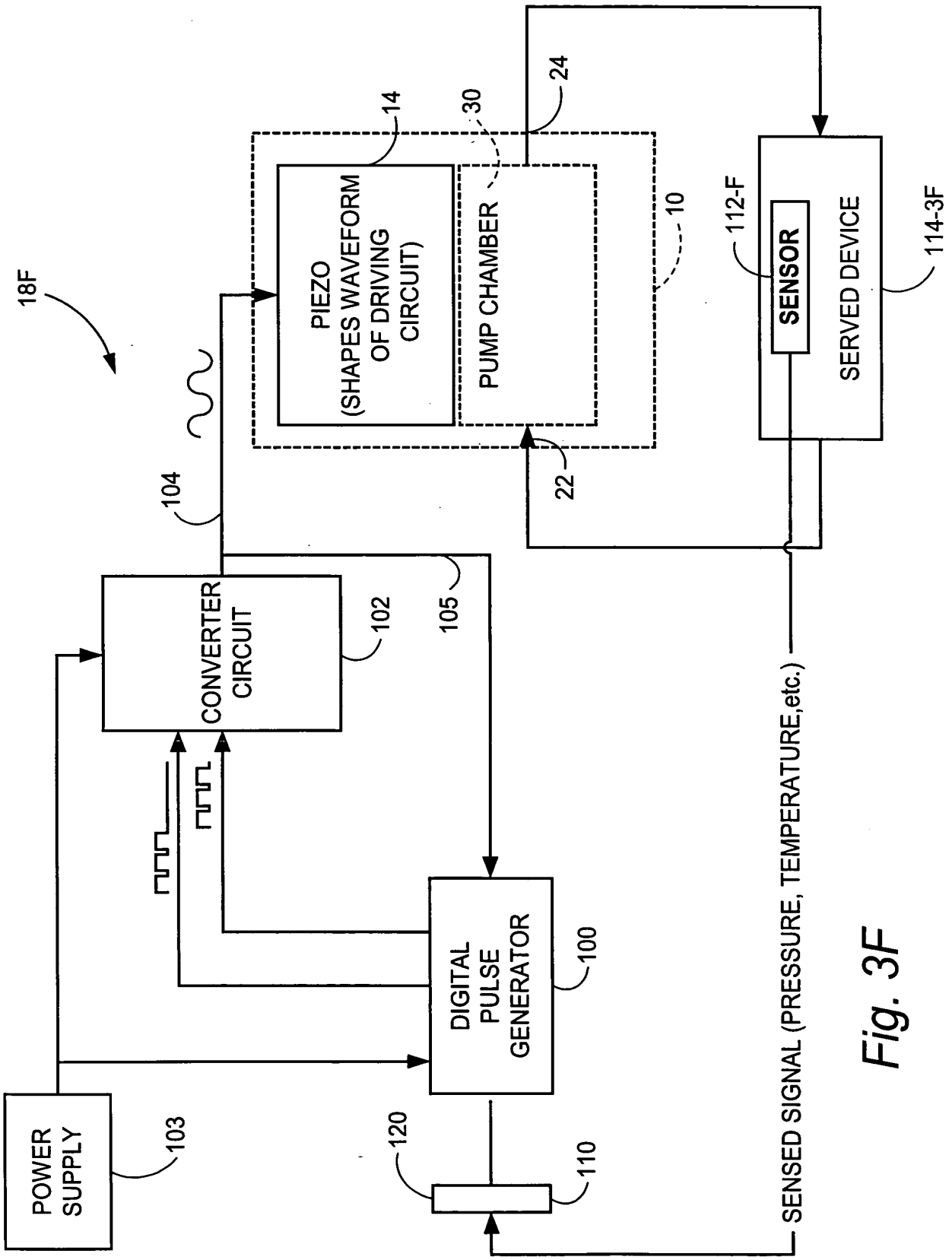

18F
PIEZO (SHAPES WAVEFORM OF DRIVING CIRCUIT)
14
30
PUMP CHAMBER
24
10
22
104
105
112-F
SENSOR
SERVED DEVICE
114-3F
CONVERTER CIRCUIT
102
DIGITAL PULSE GENERATOR
100
POWER SUPPLY
103
120
110
SENSED SIGNAL (PRESSURE, TEMPERATURE,etc.)

Fig. 3F

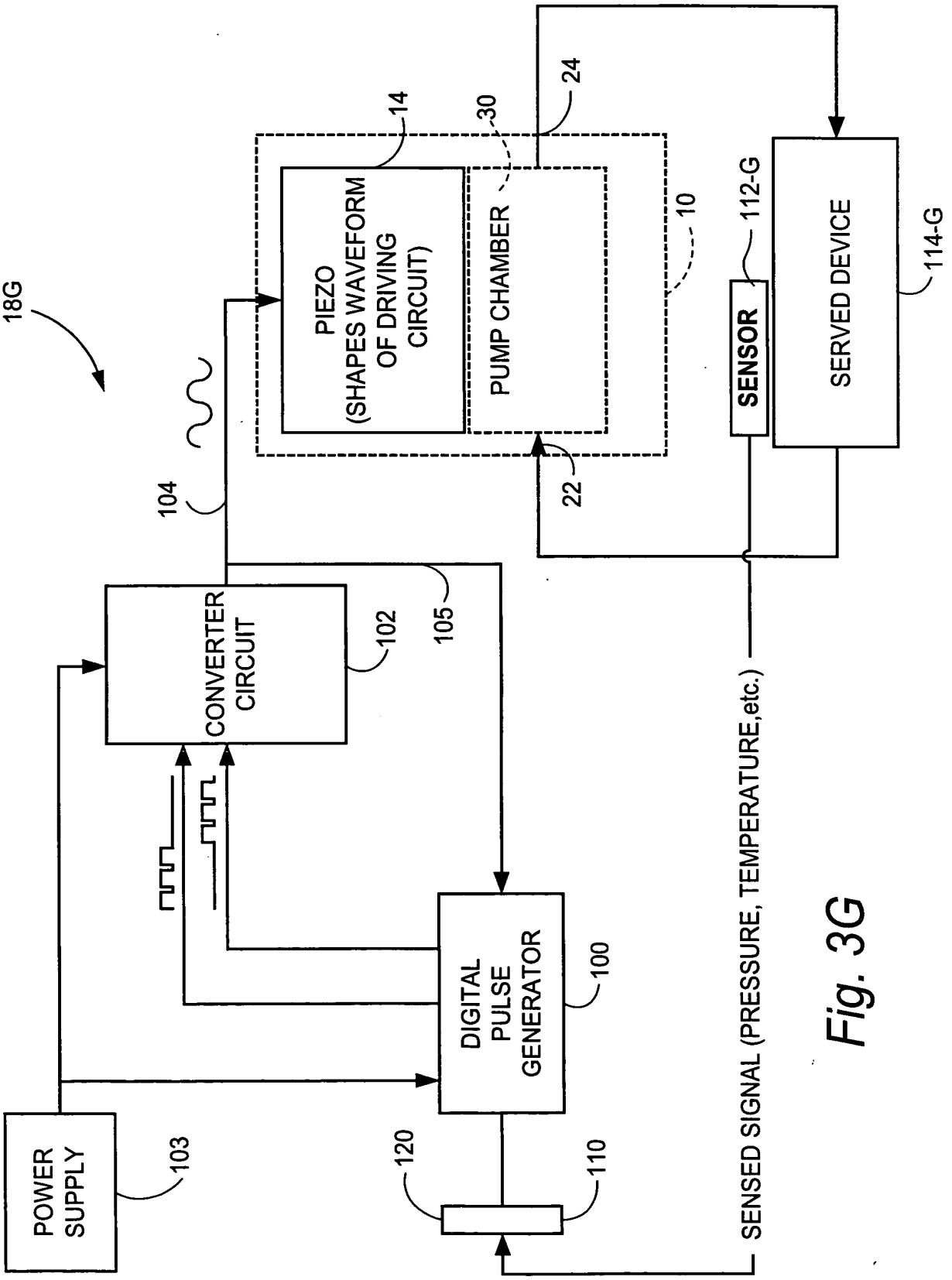

18G
PIEZO (SHAPES WAVEFORM OF DRIVING CIRCUIT)
14
PUMP CHAMBER
30
24
10
22
104
105
SENSOR
112-G
SERVED DEVICE
114-G
CONVERTER CIRCUIT
102
DIGITAL PULSE GENERATOR
100
POWER SUPPLY
103
120
110
SENSED SIGNAL (PRESSURE, TEMPERATURE,etc.)

Fig. 3G

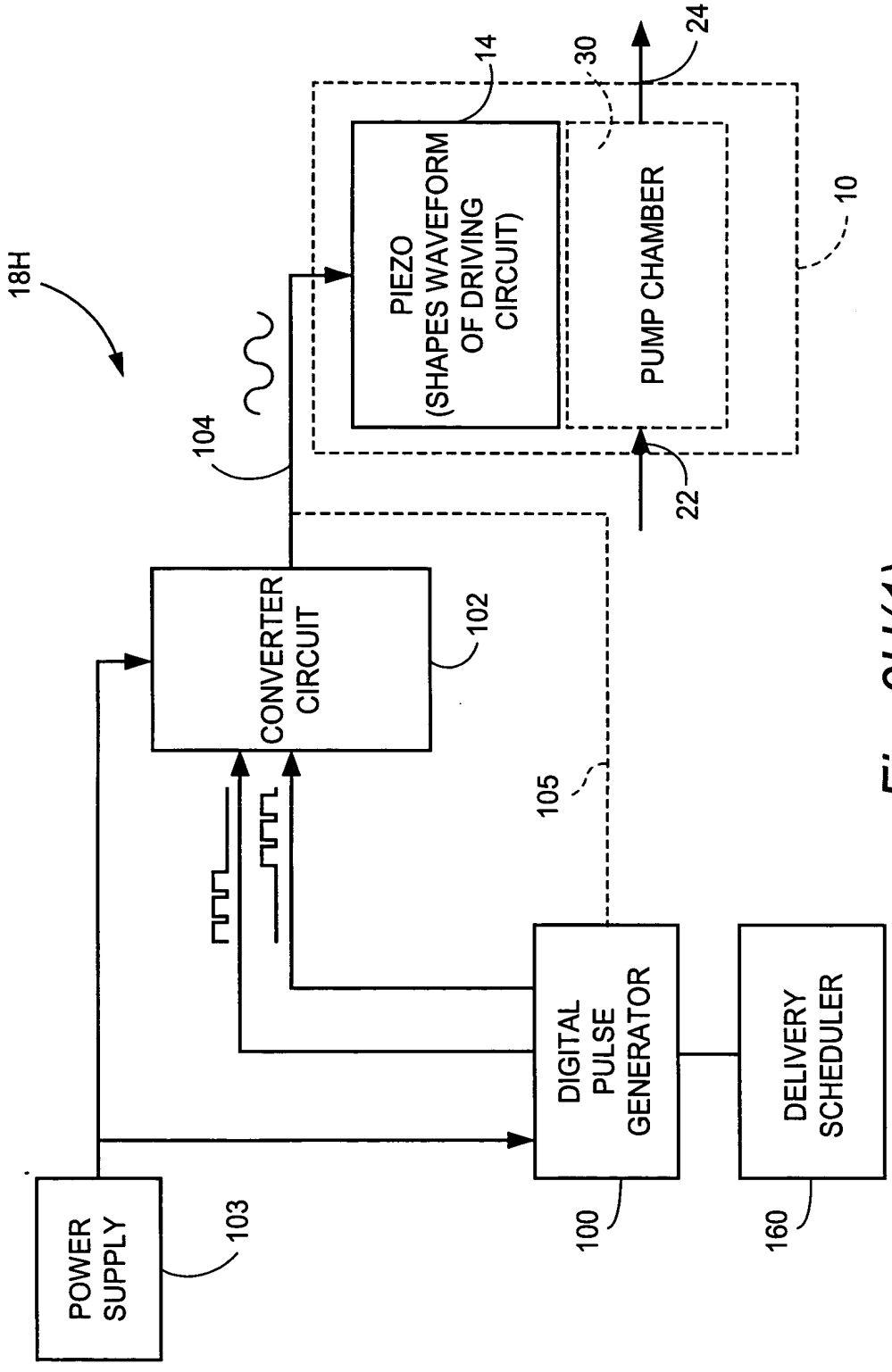

18H
104
14
PIEZO
(SHAPES WAVEFORM
OF DRIVING
CIRCUIT)
30
PUMP CHAMBER
24
10
22
CONVERTER
CIRCUIT
102
105
DIGITAL
PULSE
GENERATOR
100
DELIVERY
SCHEDULER
160
POWER
SUPPLY
103

Fig. 3H(1)

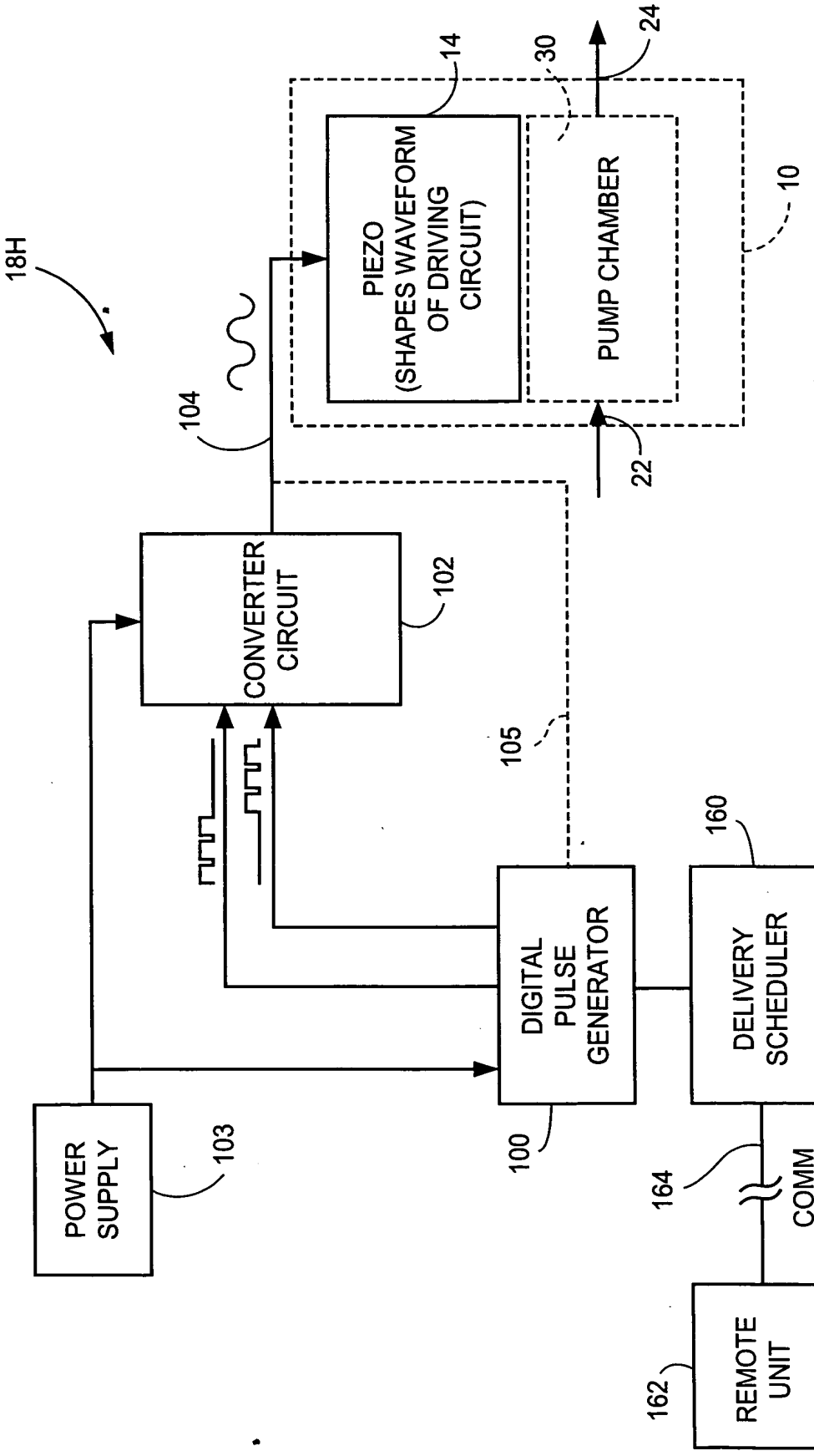

18H
PIEZO (SHAPES WAVEFORM OF DRIVING CIRCUIT)
14
PUMP CHAMBER
30
24
10
22
104
CONVERTER CIRCUIT
102
105
DIGITAL PULSE GENERATOR
100
DELIVERY SCHEDULER
160
POWER SUPPLY
103
164
COMM CHANNEL
REMOTE UNIT
162

Fig. 3H(2)

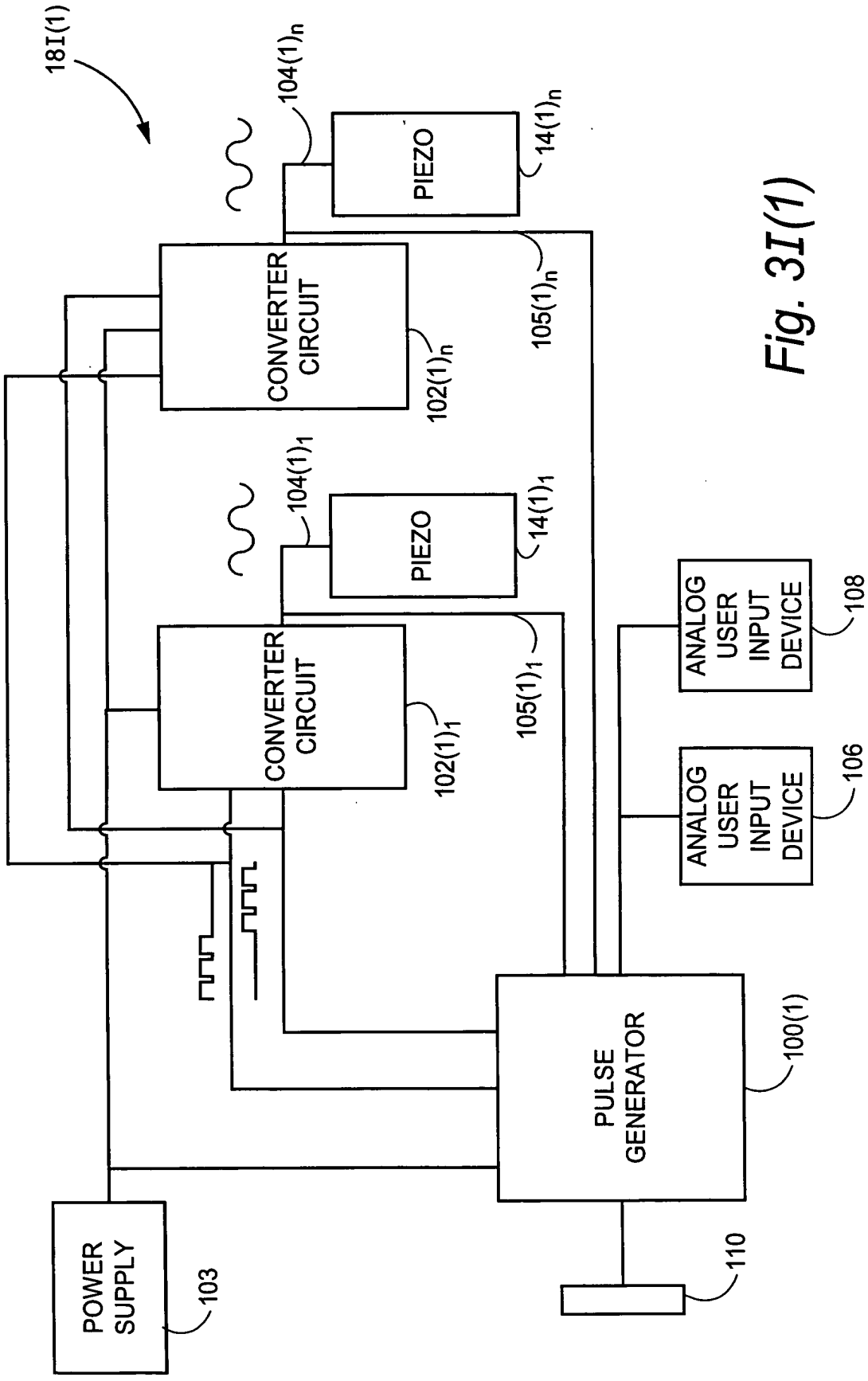

18I(1)
104(1)n
PIEZO
14(1)n
CONVERTER CIRCUIT
102(1)n
105(1)n
104(1)1
PIEZO
14(1)1
CONVERTER CIRCUIT
102(1)1
105(1)1
ANALOG USER INPUT DEVICE
108
ANALOG USER INPUT DEVICE
106
PULSE GENERATOR
100(1)
POWER SUPPLY
103
110

Fig. 3I(1)

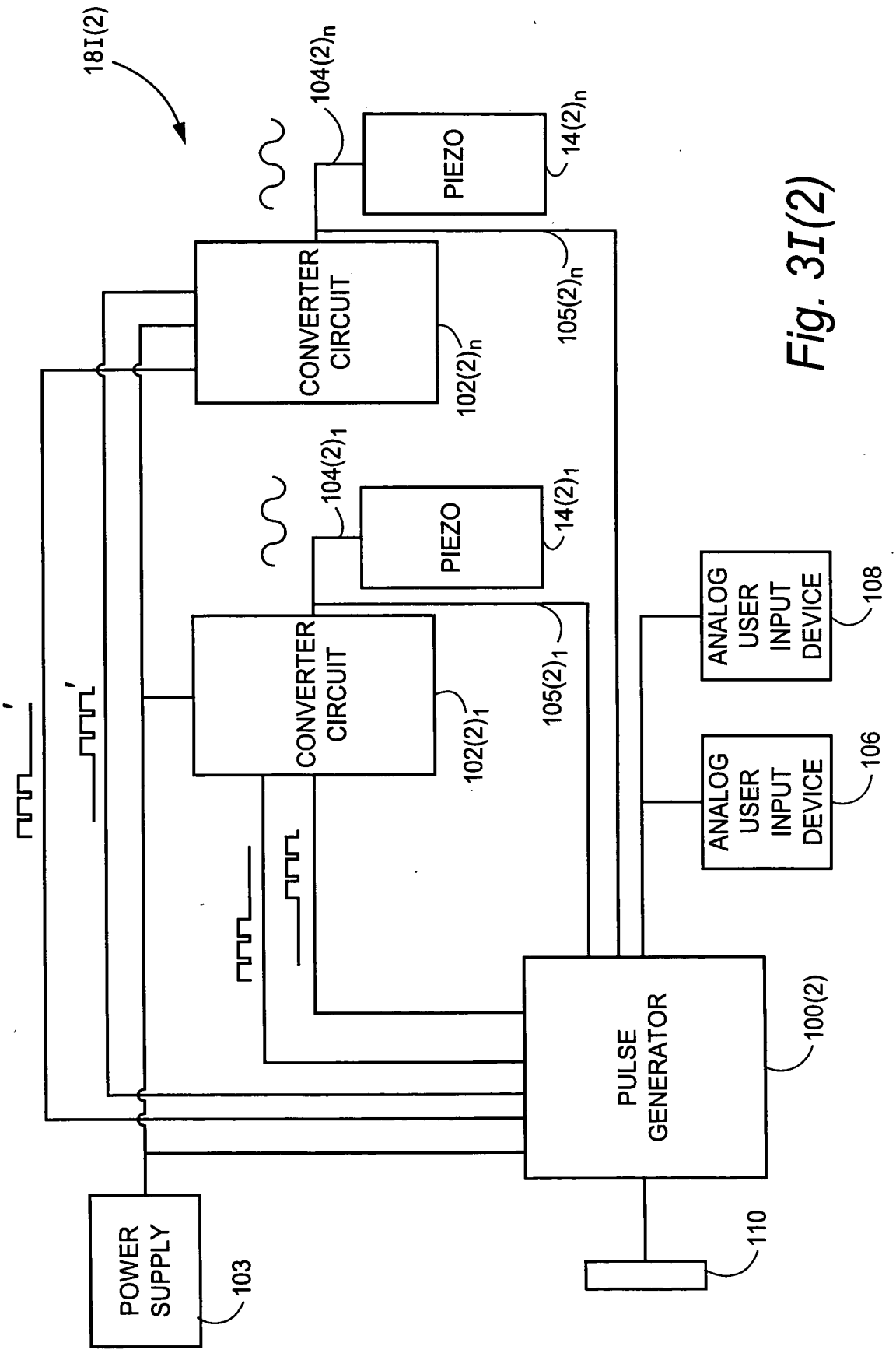

18I(2)
104(2)n
PIEZO
14(2)n
CONVERTER CIRCUIT
102(2)n
105(2)n
104(2)1
PIEZO
14(2)1
CONVERTER CIRCUIT
102(2)1
105(2)1
ANALOG USER INPUT DEVICE
108
ANALOG USER INPUT DEVICE
106
PULSE GENERATOR
100(2)
POWER SUPPLY
103
110

Fig. 3I(2)

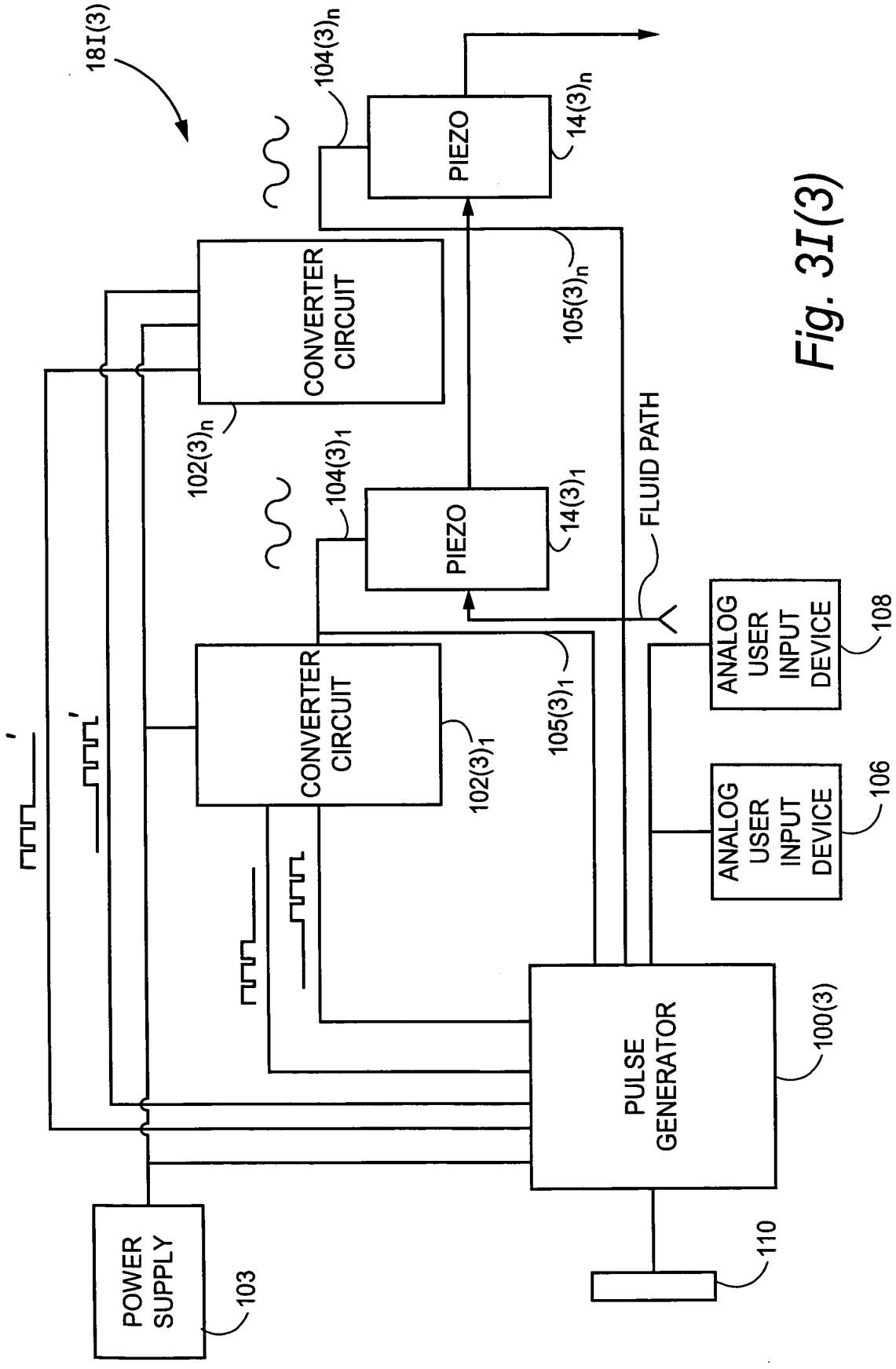

18I(3)
104(3)n
PIEZO
14(3)n
CONVERTER CIRCUIT
105(3)n
102(3)n
104(3)1
PIEZO
14(3)1
FLUID PATH
CONVERTER CIRCUIT
102(3)1
105(3)1
ANALOG USER INPUT DEVICE
108
ANALOG USER INPUT DEVICE
106
PULSE GENERATOR
100(3)
POWER SUPPLY
103
110

Fig. 3I(3)

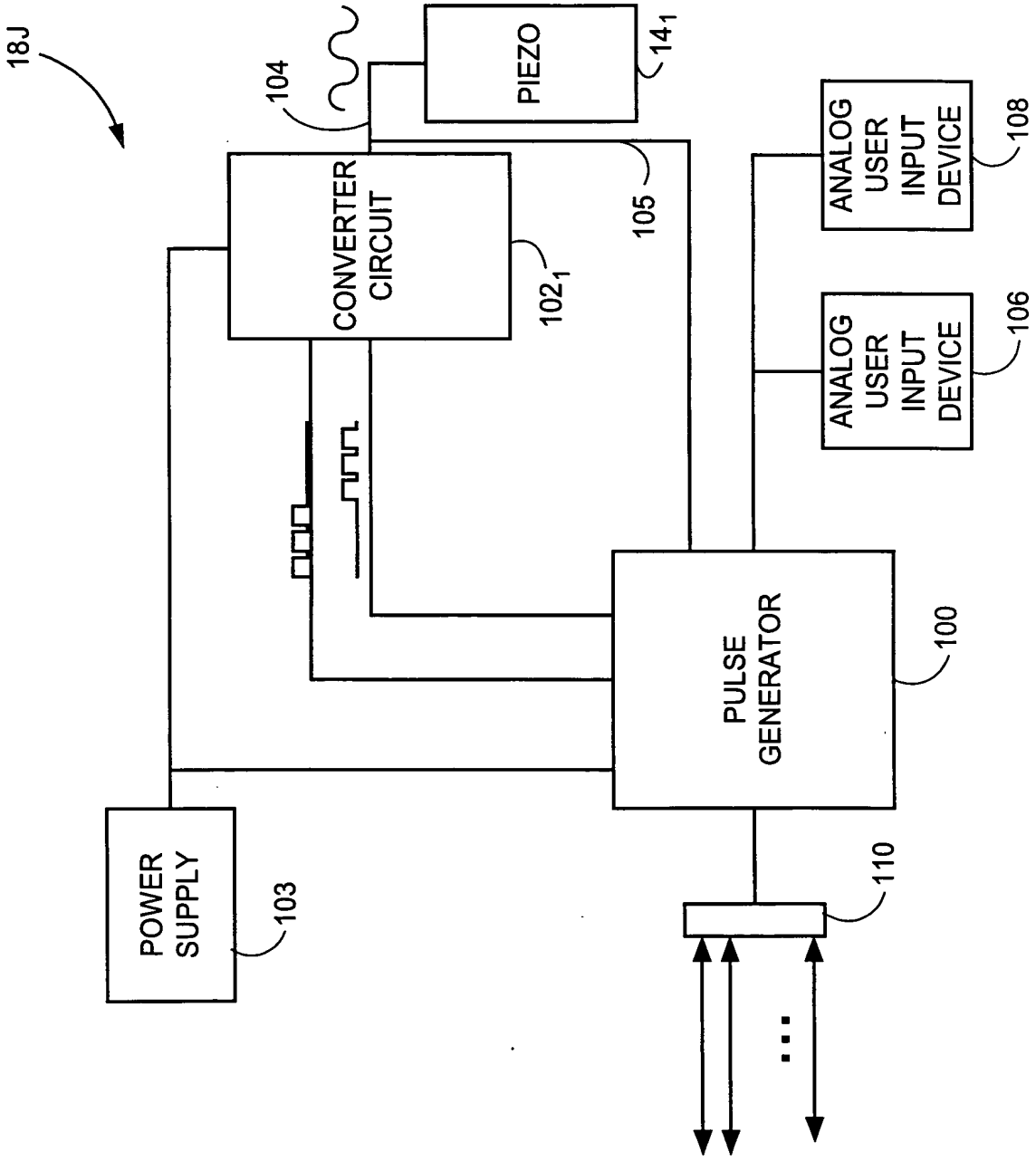

18J
104
PIEZO
14_1
CONVERTER CIRCUIT
102_1
105
ANALOG USER INPUT DEVICE
108
ANALOG USER INPUT DEVICE
106
PULSE GENERATOR
100
POWER SUPPLY
103
110

Fig. 3J

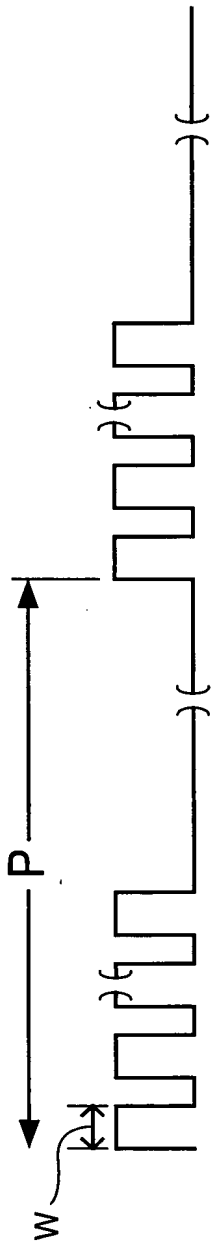


Fig. 4A

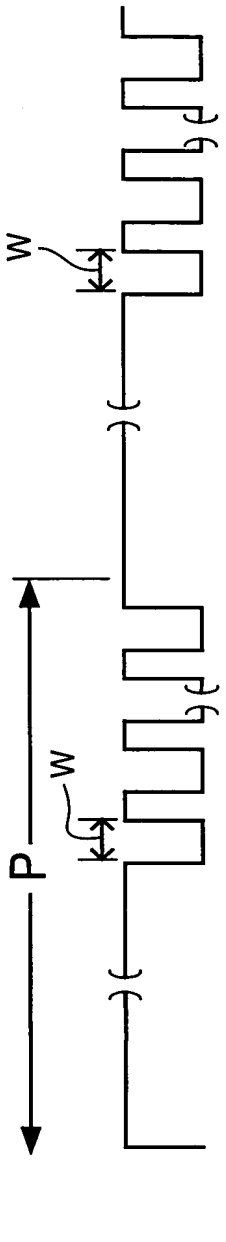


Fig. 4B

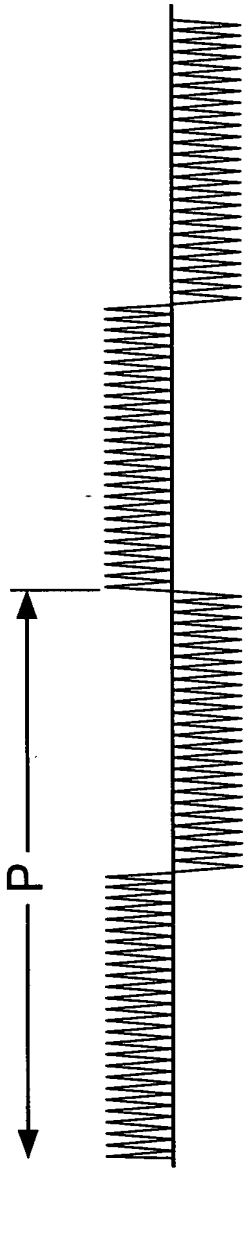


Fig. 4C

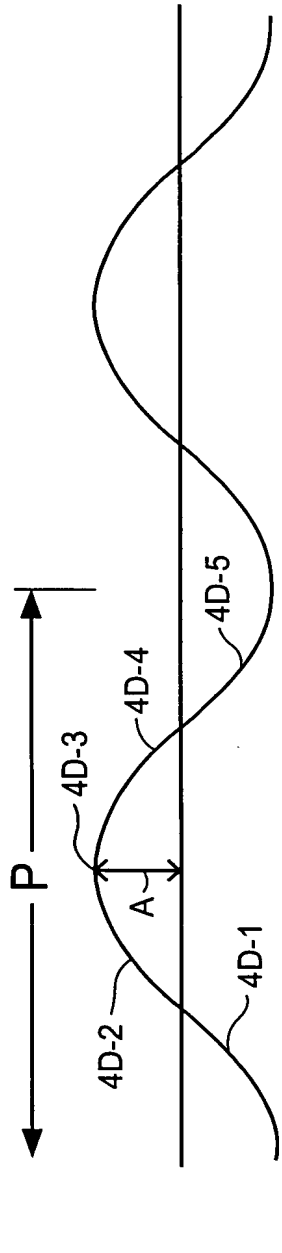


Fig. 4D

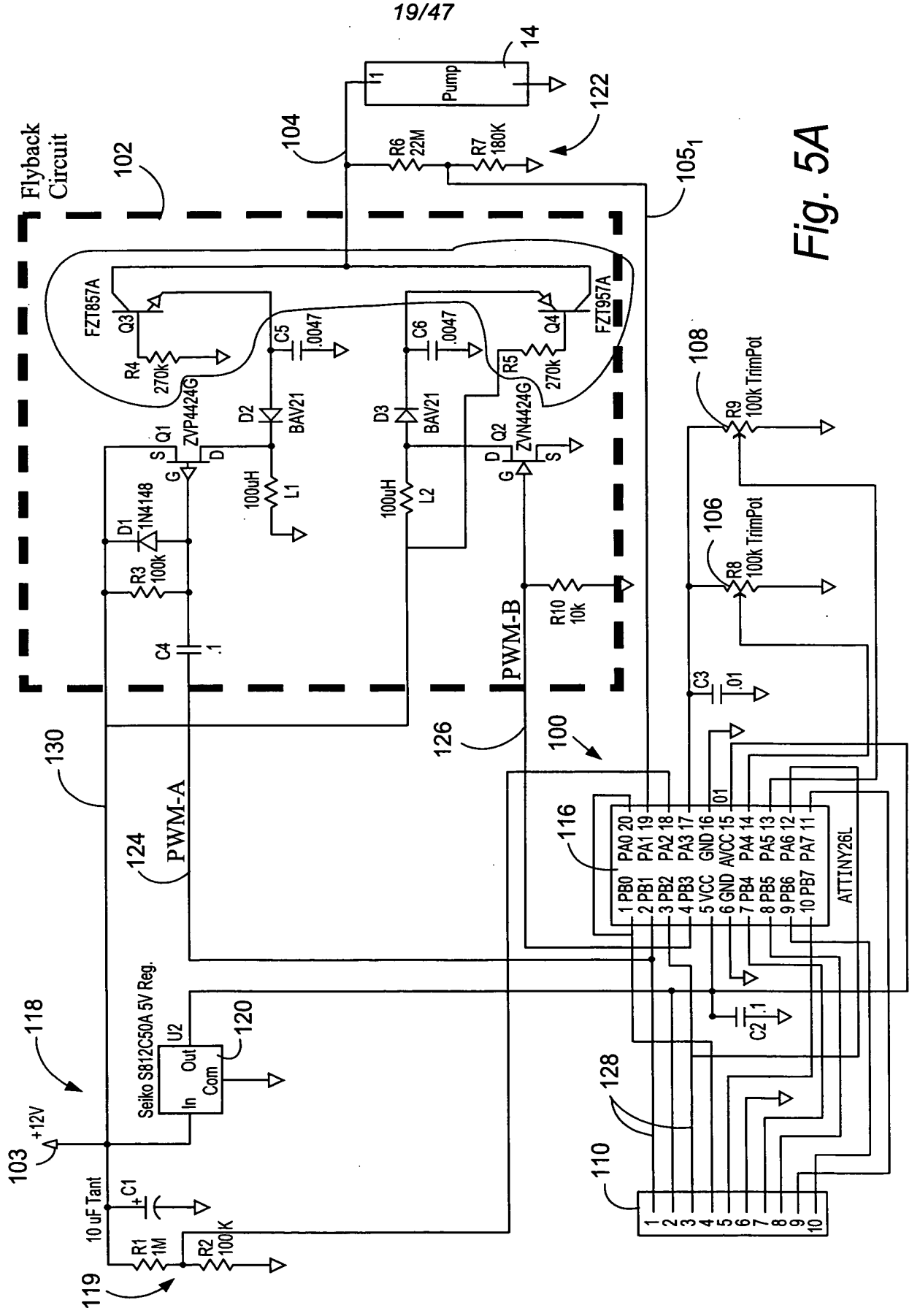

Flyback Circuit
102
104
105
122
14
Pump
R6 22M
R7 180K
FZT857A
Q3
R4 270k
C5 .0047
D2 BAV21
Q1 ZVP4424G
D1 1N4148
R3 100k
C4 .1
100uH L1
C6 .0047
D3 BAV21
R5 270k
Q4 FZT957A
Q2 ZVN4424G
100uH L2
R10 10k
PWM-B
126
100
108
R9 100k TrimPot
106
R8 100k TrimPot
C3 .01
130
PWM-A
124
116
1 PB0 PA0 20
2 PB1 PA1 19
3 PB2 PA2 18
4 PB3 PA3 17
5 VCC GND 16
6 GND AVCC 15
7 PB4 PA4 14
8 PB5 PA5 13
9 PB6 PA6 12
10 PB7 PA7 11
ATTINY26L
118
Seiko S812C50A 5V Reg.
U2
In Out Com
120
C2 .1
128
110
1 2 3 4 5 6 7 8 9 10
103
+12V
C1
10 uF Tant
R1 1M
R2 100K
119

Fig. 5A

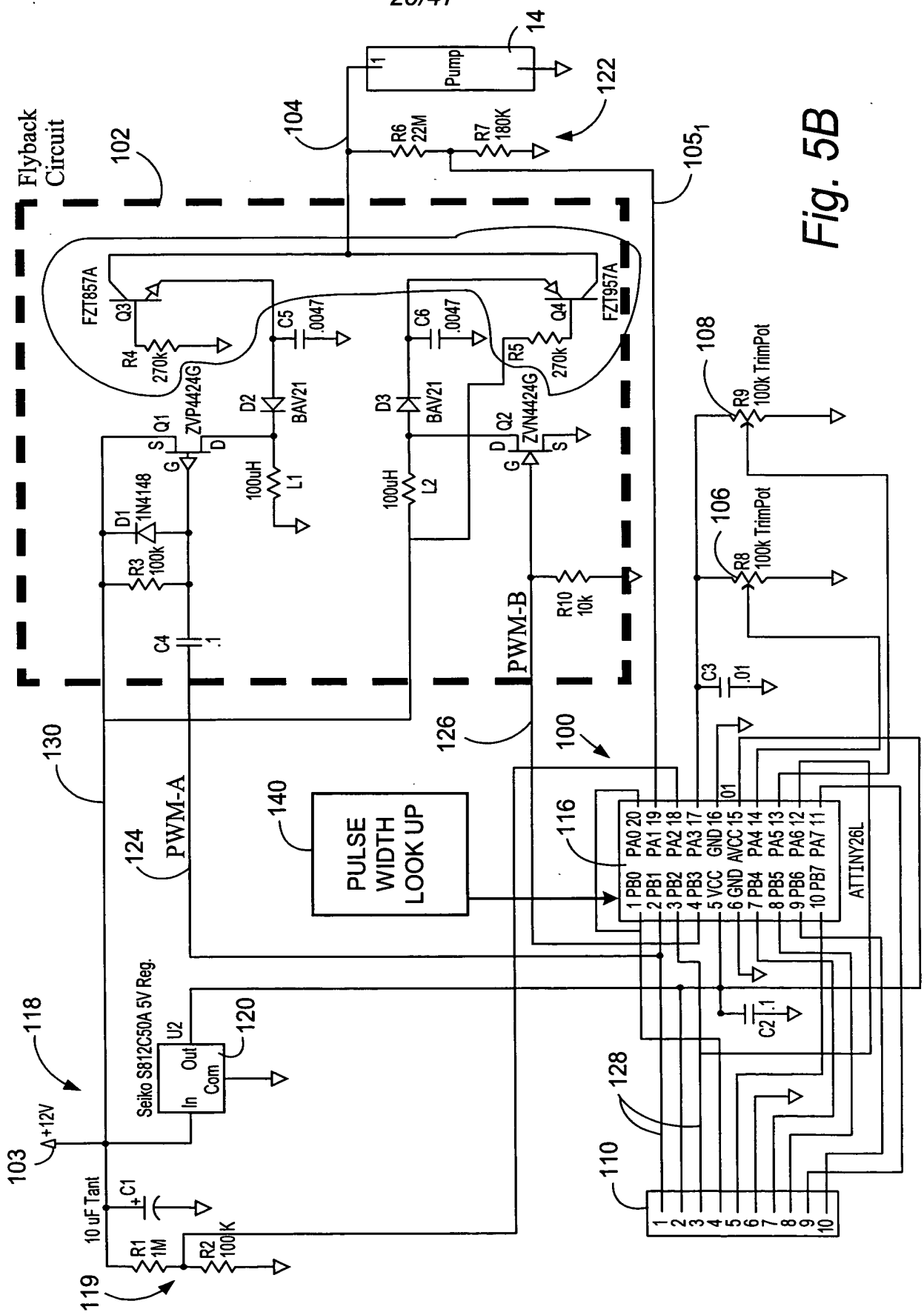

Flyback Circuit
102
104
105
122
14
Pump
R6 22M
R7 180K
FZT857A
Q3
FZT957A
Q4
R4 270k
R5 270k
C5 .0047
C6 .0047
D2 BAV21
D3 BAV21
Q1 ZVP4424G
Q2 ZVN4424G
100uH L1
100uH L2
D1 1N4148
R3 100k
C4 .1
R10 10k
PWM-B
PWM-A
108
R9 100k TrimPot
106
R8 100k TrimPot
C3 .01
126
100
130
140
PULSE WIDTH LOOK UP
124
116
PA0 20
PA1 19
PA2 18
PA3 17
GND 16
AVCC 15
PA4 14
PA5 13
PA6 12
PA7 11
PB0 1
PB1 2
PB2 3
PB3 4
VCC 5
GND 6
PB4 7
PB5 8
PB6 9
PB7 10
ATTINY26L
118
+12V
103
Seiko S812C50A 5V Reg.
U2
In
Out
Com
120
C1 10 uF Tant
R1 1M
R2 100K
119
C2 .1
128
110
1 2 3 4 5 6 7 8 9 10

Fig. 5B

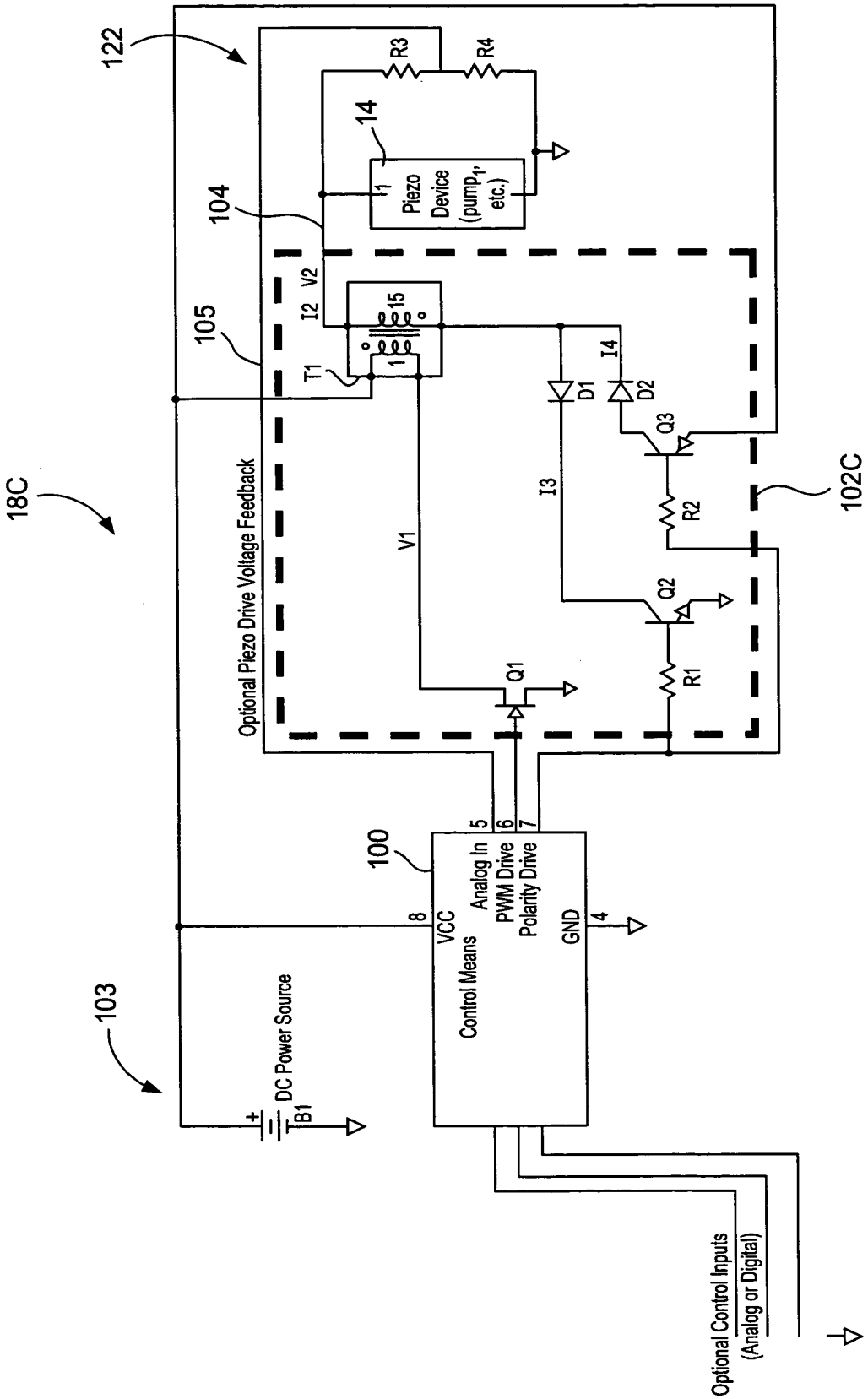

18C
122
R3
R4
14
Piezo Device (pump1, etc.)
104
105
V2
I2
15
T1
1
I4
D1
D2
Q3
I3
R2
102C
V1
Q2
Q1
R1
Optional Piezo Drive Voltage Feedback
100
5
6
7
8
VCC
Analog In
PWM Drive
Polarity Drive
GND
4
Control Means
103
DC Power Source
B1
Optional Control Inputs (Analog or Digital)

Fig. 5C

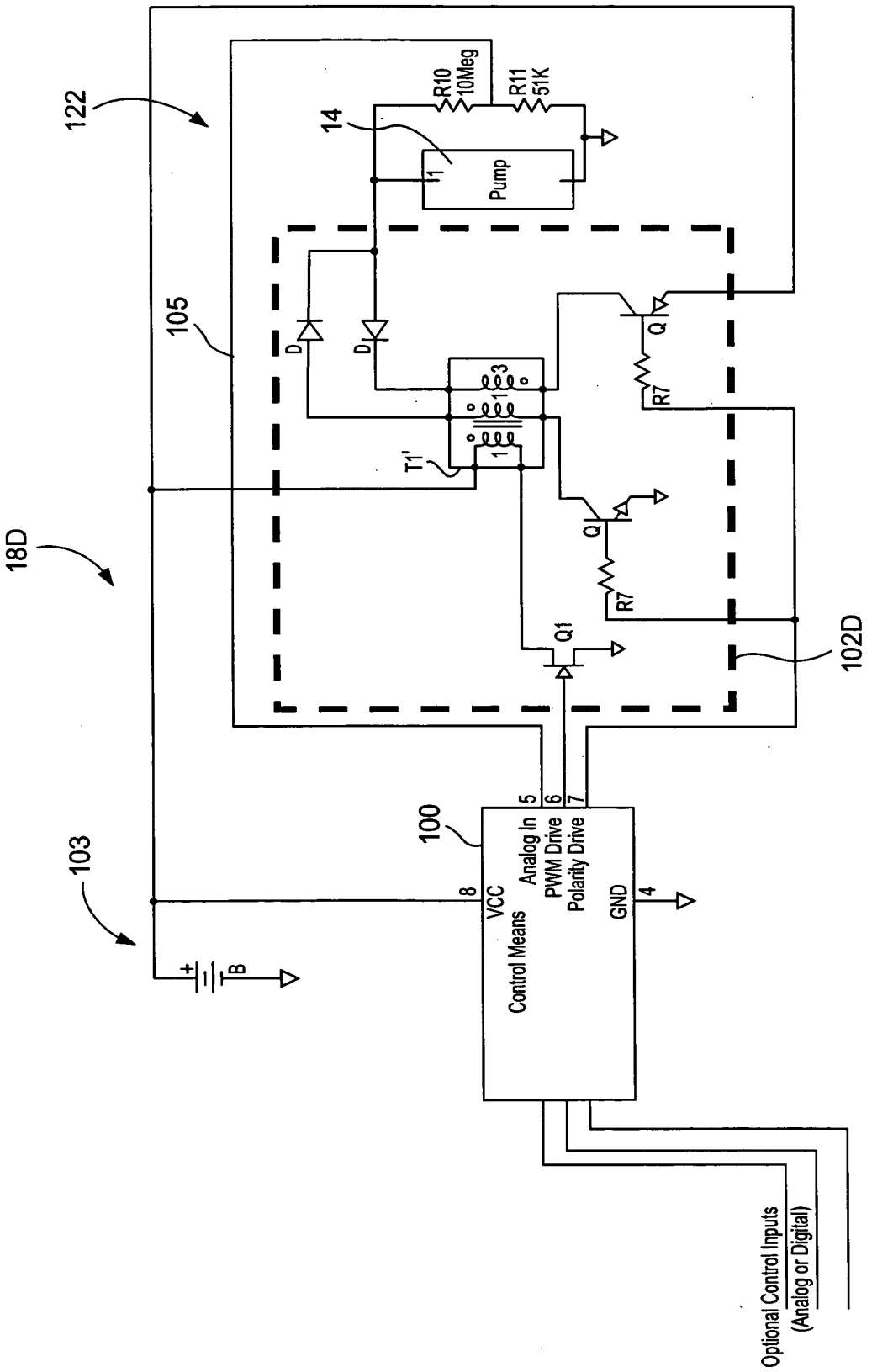

122
14
R10
10Meg
R11
51K
11
Pump
105
D
D
T1'
13
11
1
Q
R7
Q
R7
18D
Q1
102D
100
103
5
6
7
8
4
Analog In
PWM Drive
Polarity Drive
VCC
GND
Control Means
B
Optional Control Inputs
(Analog or Digital)

Fig. 5D

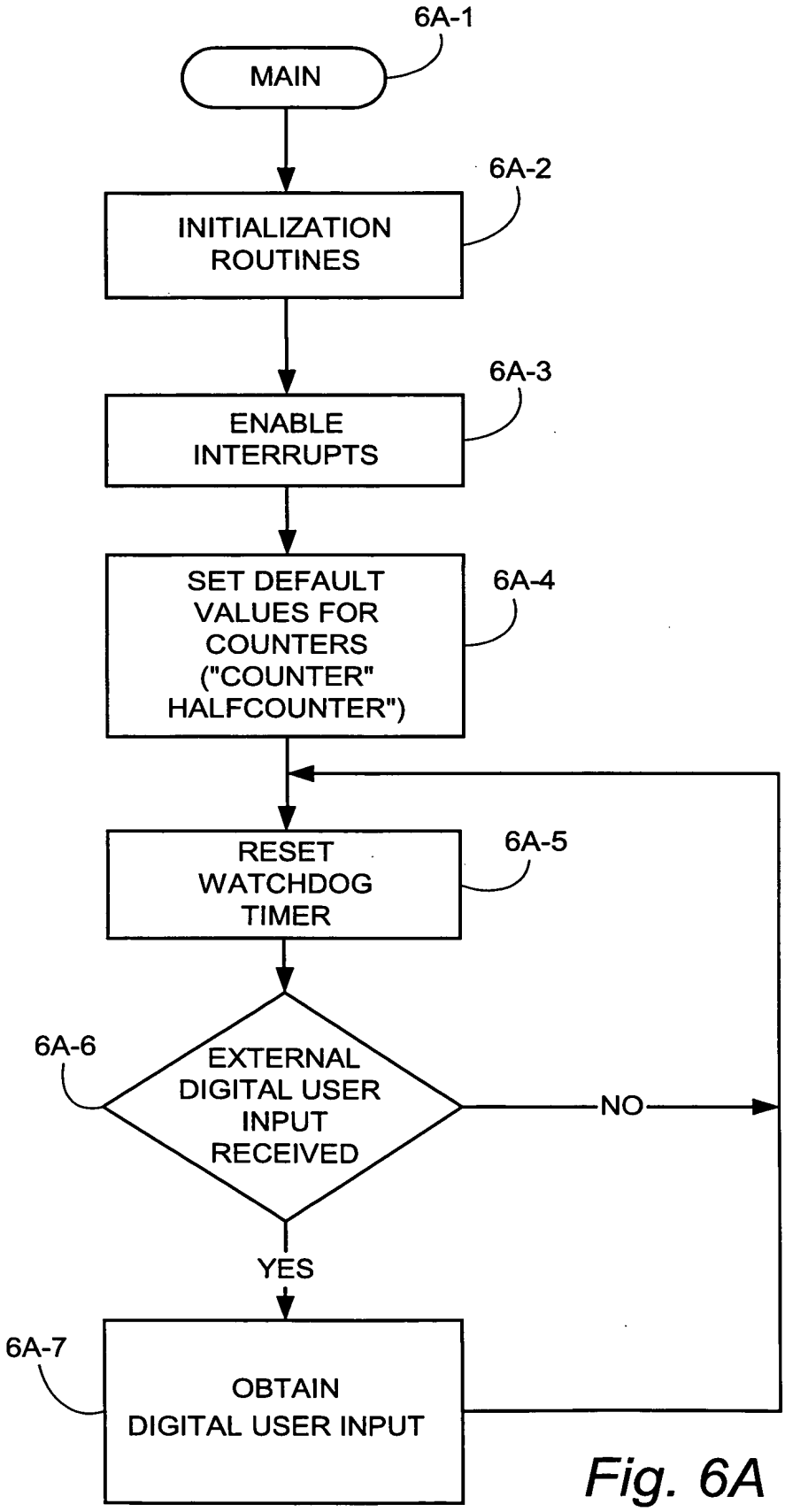

6A-1
MAIN
6A-2
INITIALIZATION ROUTINES
6A-3
ENABLE INTERRUPTS
6A-4
SET DEFAULT VALUES FOR COUNTERS ("COUNTER" HALFCOUNTER")
6A-5
RESET WATCHDOG TIMER
6A-6
EXTERNAL DIGITAL USER INPUT RECEIVED
NO
YES
6A-7
OBTAIN DIGITAL USER INPUT

Fig. 6A

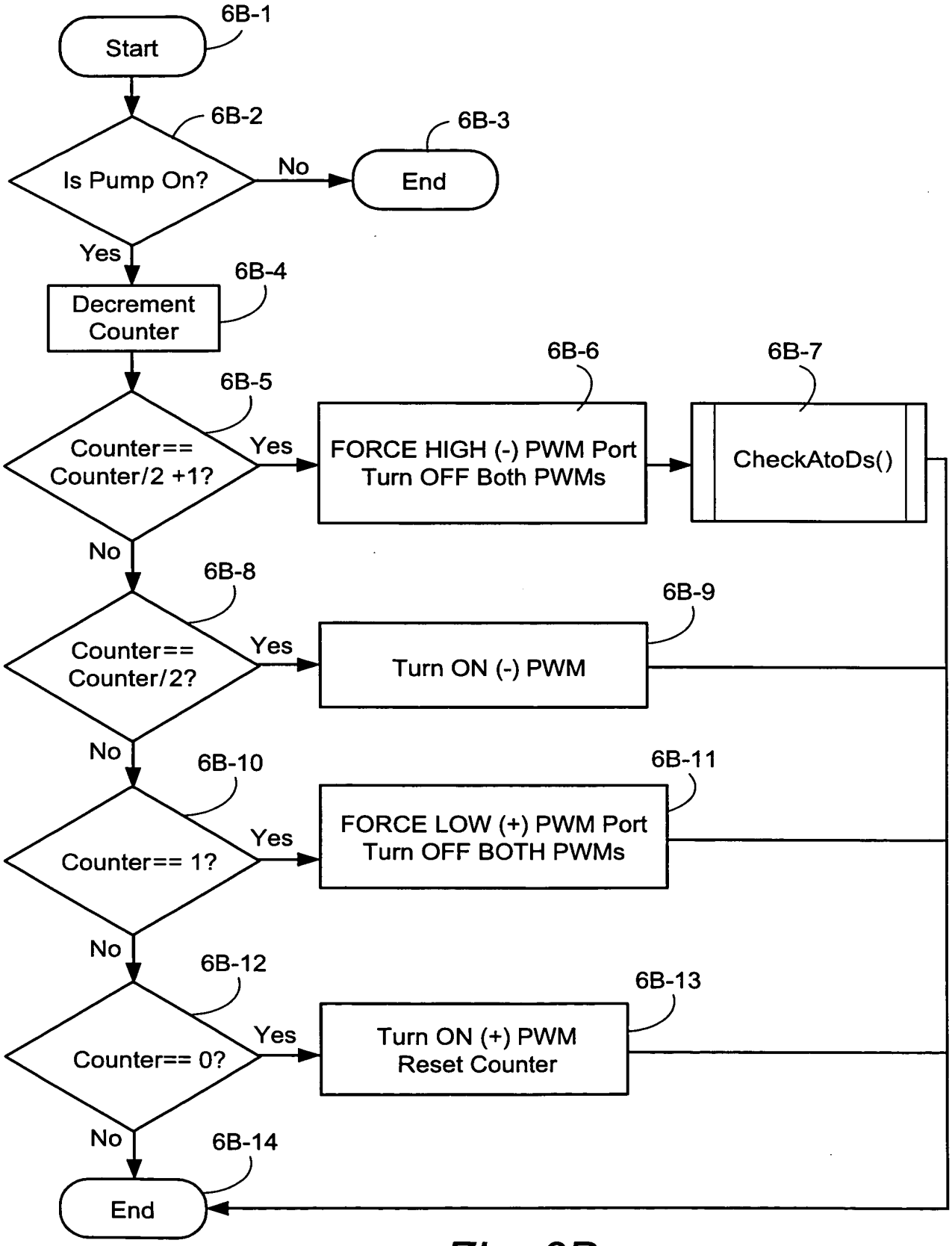

6B-1
Start
6B-2
Is Pump On?
No
6B-3
End
Yes
6B-4
Decrement Counter
6B-5
Counter== Counter/2 +1?
Yes
6B-6
FORCE HIGH (-) PWM Port
Turn OFF Both PWMs
6B-7
CheckAtoDs()
No
6B-8
Counter== Counter/2?
Yes
6B-9
Turn ON (-) PWM
No
6B-10
Counter== 1?
Yes
6B-11
FORCE LOW (+) PWM Port
Turn OFF BOTH PWMs
No
6B-12
Counter== 0?
Yes
6B-13
Turn ON (+) PWM
Reset Counter
No
6B-14
End

Fig. 6B

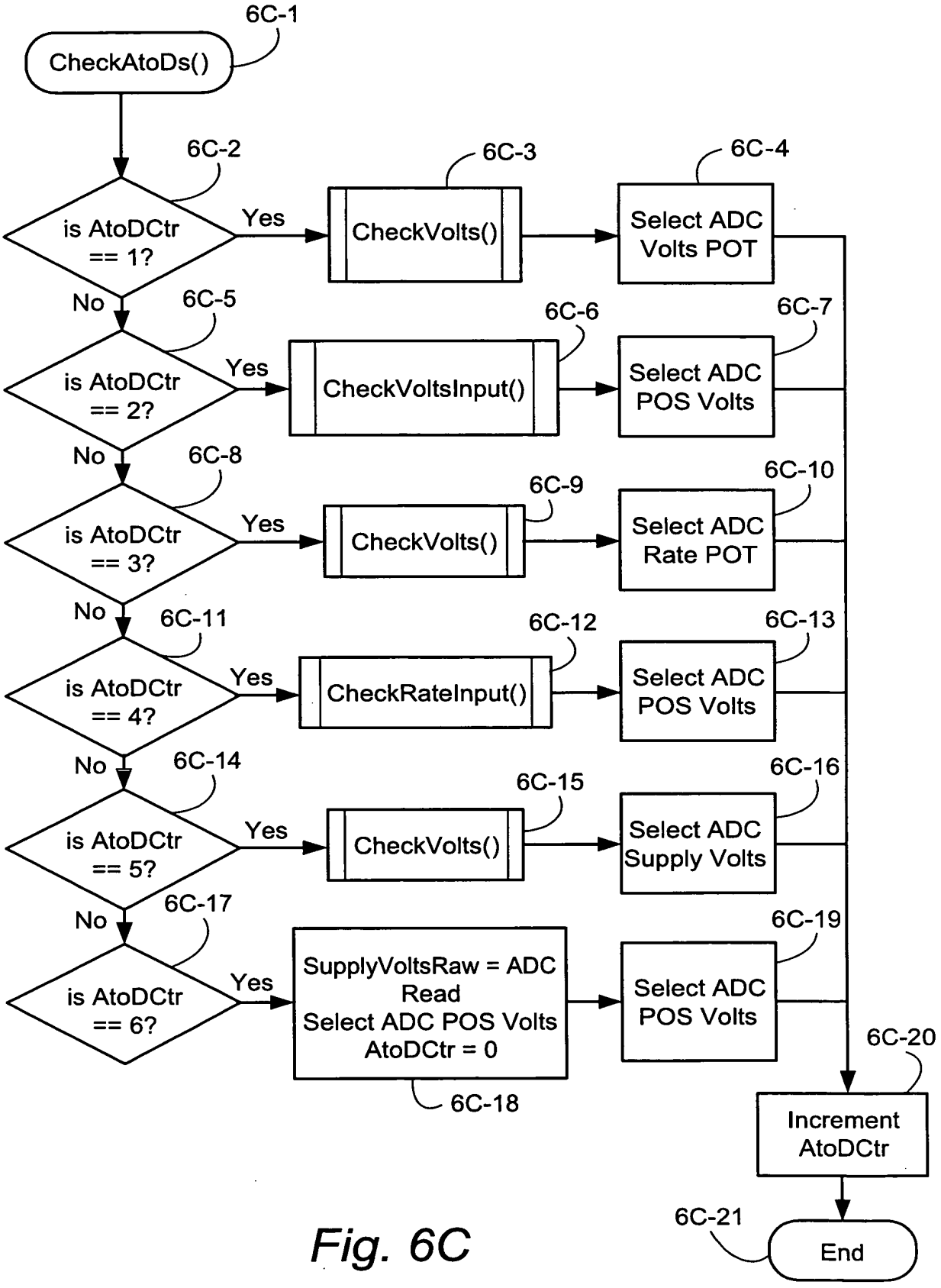

6C-1
CheckAtoDs()
6C-2
is AtoDCtr == 1?
Yes
6C-3
CheckVolts()
6C-4
Select ADC Volts POT
No
6C-5
is AtoDCtr == 2?
Yes
6C-6
CheckVoltsInput()
6C-7
Select ADC POS Volts
No
6C-8
is AtoDCtr == 3?
Yes
6C-9
CheckVolts()
6C-10
Select ADC Rate POT
No
6C-11
is AtoDCtr == 4?
Yes
6C-12
CheckRateInput()
6C-13
Select ADC POS Volts
No
6C-14
is AtoDCtr == 5?
Yes
6C-15
CheckVolts()
6C-16
Select ADC Supply Volts
No
6C-17
is AtoDCtr == 6?
Yes
SupplyVoltsRaw = ADC Read
Select ADC POS Volts
AtoDCtr = 0
6C-18
6C-19
Select ADC POS Volts
6C-20
Increment AtoDCtr
6C-21
End

Fig. 6C

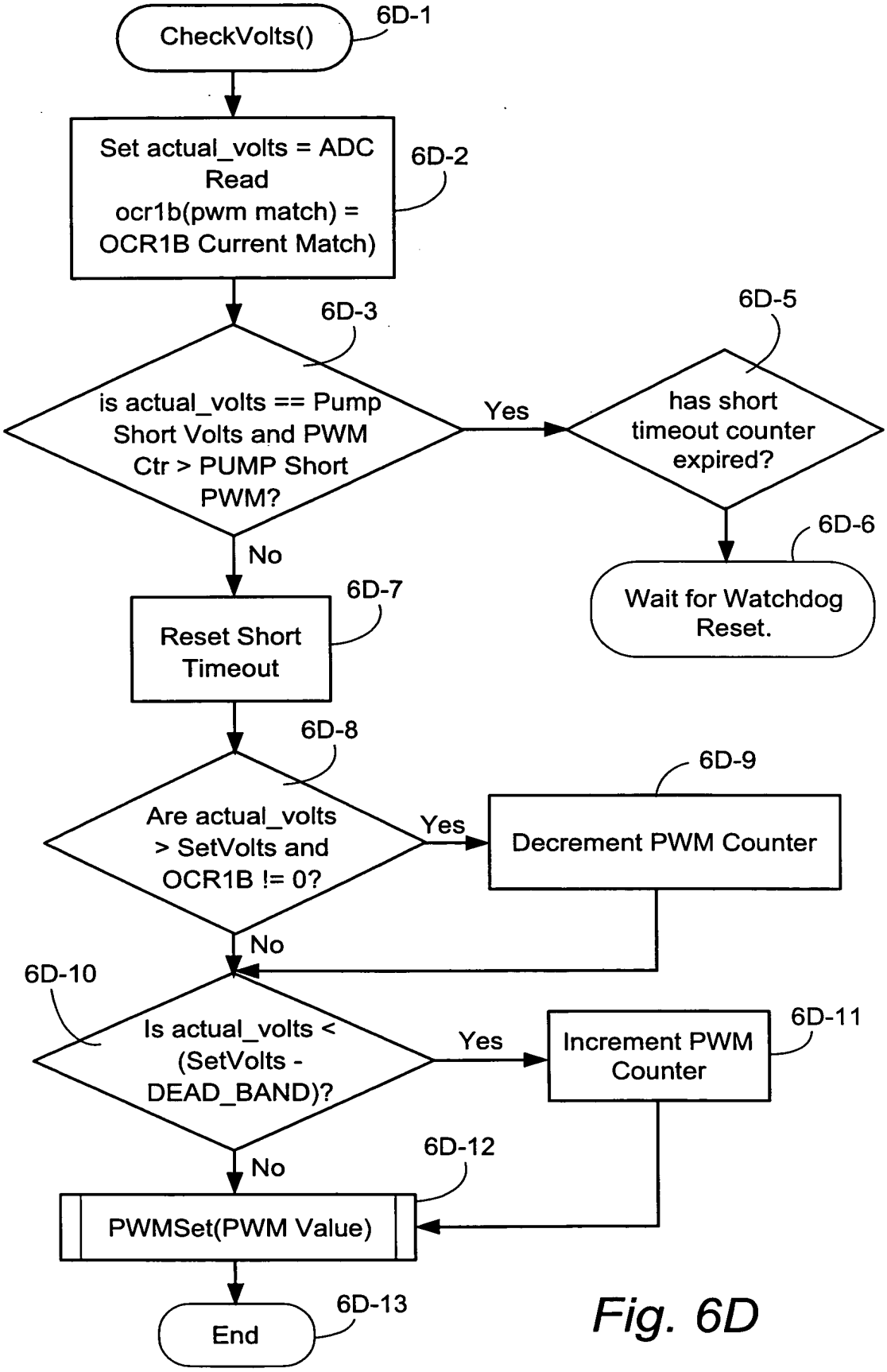

CheckVolts()
6D-1
Set actual_volts = ADC Read
ocr1b(pwm match) = OCR1B Current Match)
6D-2
6D-3
is actual_volts == Pump Short Volts and PWM Ctr > PUMP Short PWM?
Yes
6D-5
has short timeout counter expired?
6D-6
Wait for Watchdog Reset.
No
6D-7
Reset Short Timeout
6D-8
Are actual_volts > SetVolts and OCR1B != 0?
Yes
6D-9
Decrement PWM Counter
No
6D-10
Is actual_volts < (SetVolts - DEAD_BAND)?
Yes
Increment PWM Counter
6D-11
No
6D-12
PWMSet(PWM Value)
End
6D-13

Fig. 6D

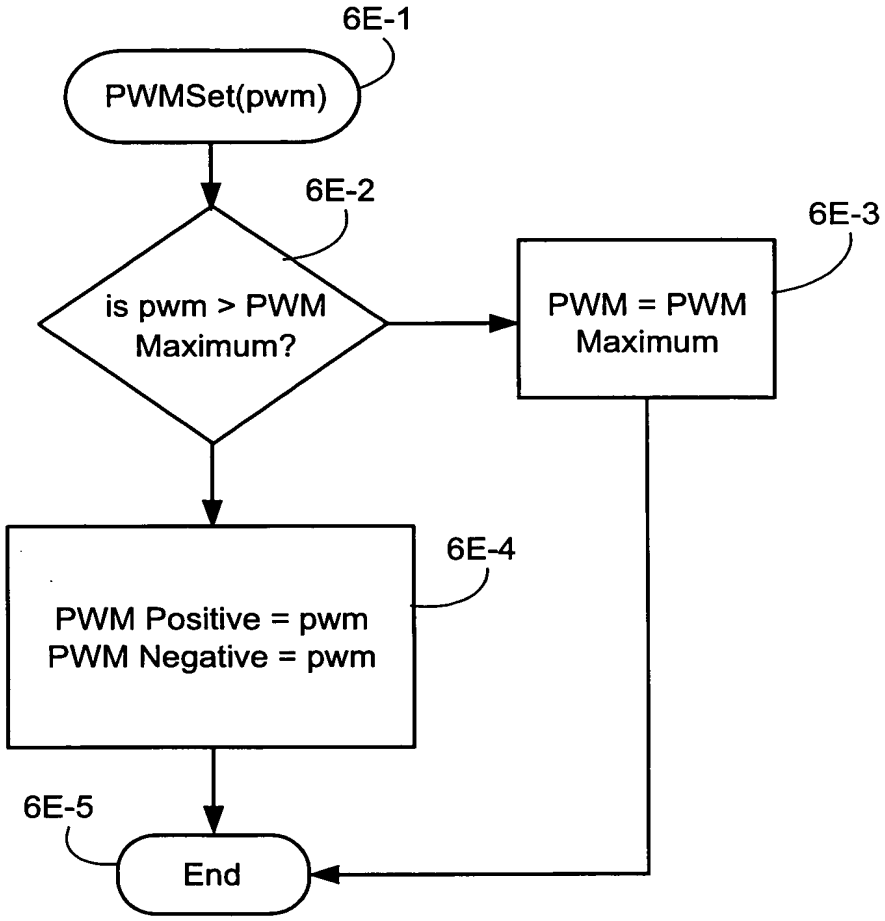

6E-1
PWMSet(pwm)
6E-2
is pwm > PWM Maximum?
6E-3
PWM = PWM Maximum
6E-4
PWM Positive = pwm
PWM Negative = pwm
6E-5
End

Fig. 6E

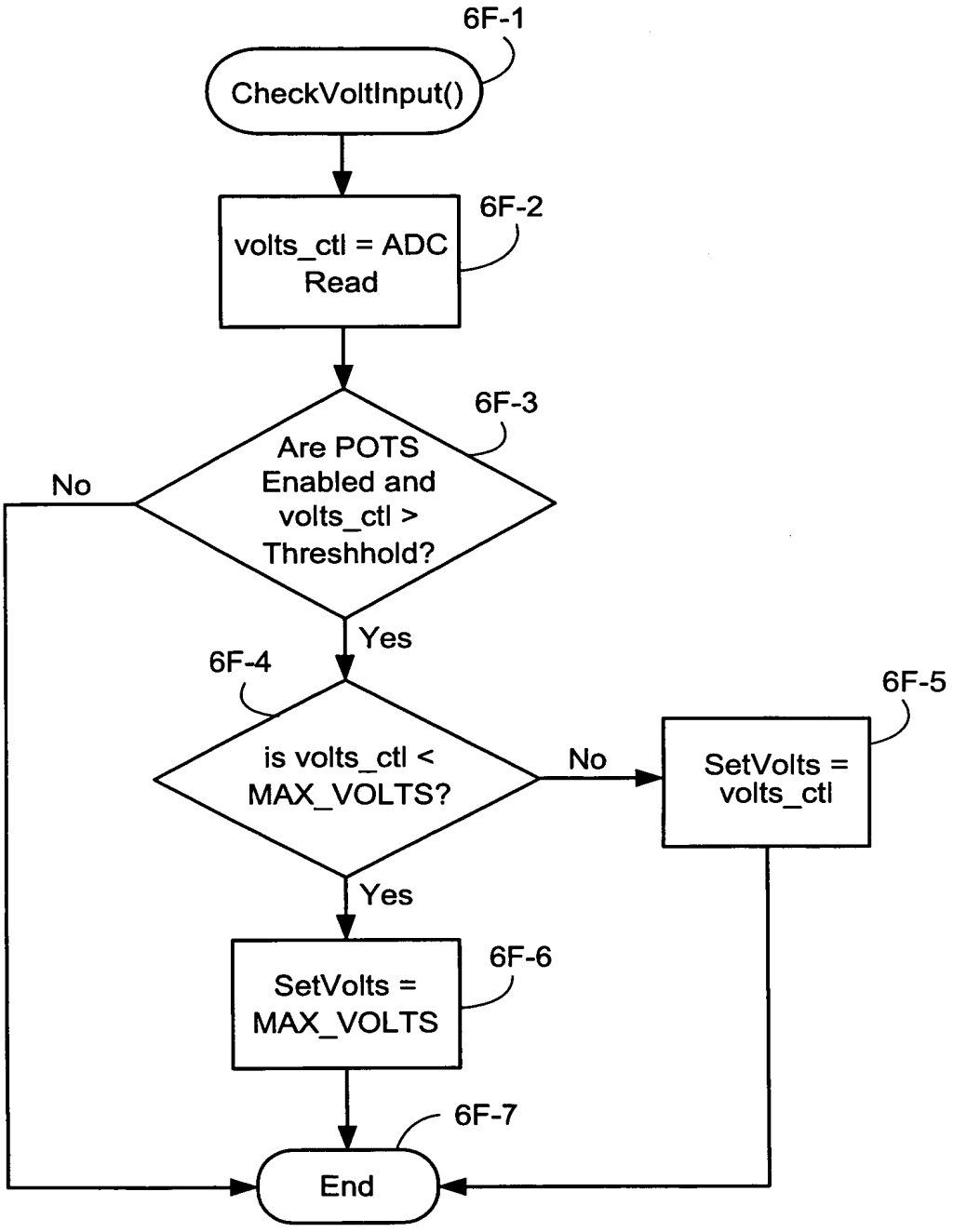

6F-1
CheckVoltInput()
6F-2
volts_ctl = ADC Read
6F-3
Are POTS Enabled and volts_ctl > Threshhold?
No
Yes
6F-4
is volts_ctl < MAX_VOLTS?
No
6F-5
SetVolts = volts_ctl
Yes
6F-6
SetVolts = MAX_VOLTS
6F-7
End

Fig. 6F

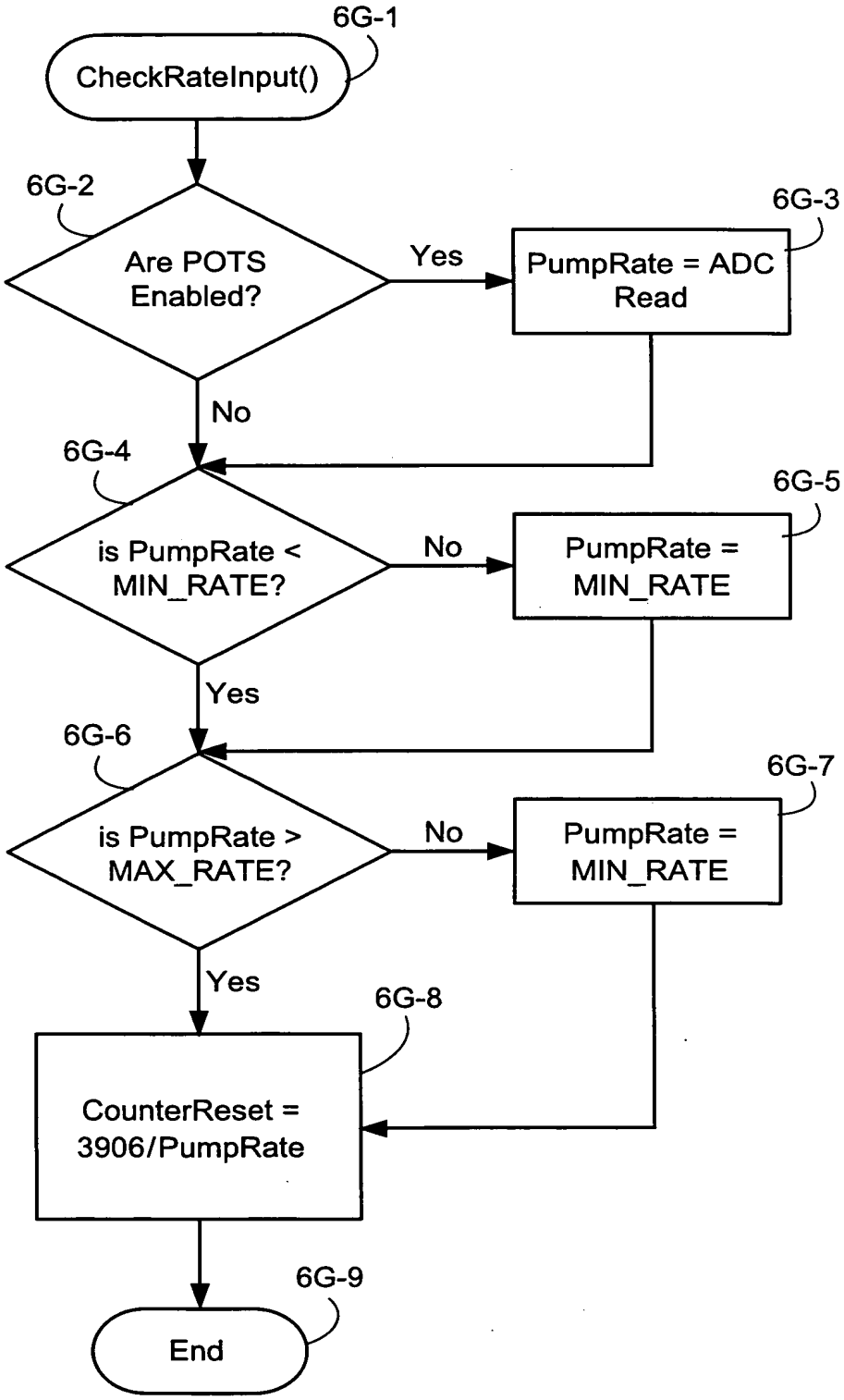

6G-1
CheckRateInput()
6G-2
Are POTS Enabled?
Yes
6G-3
PumpRate = ADC Read
No
6G-4
is PumpRate < MIN_RATE?
No
6G-5
PumpRate = MIN_RATE
Yes
6G-6
is PumpRate > MAX_RATE?
No
6G-7
PumpRate = MIN_RATE
Yes
6G-8
CounterReset = 3906/PumpRate
6G-9
End

Fig. 6G

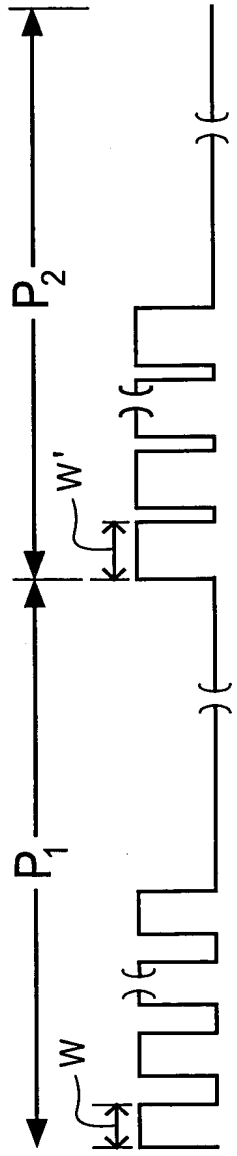


Fig. 7A

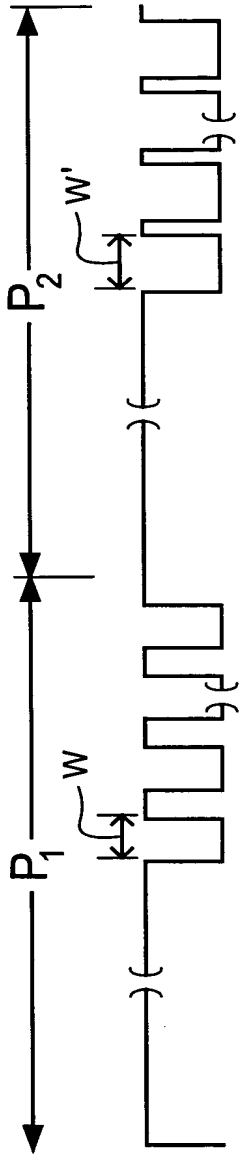


Fig. 7B

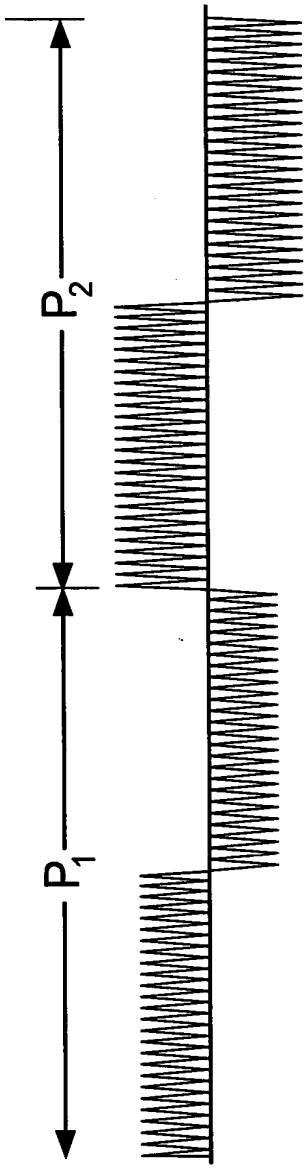


Fig. 7C

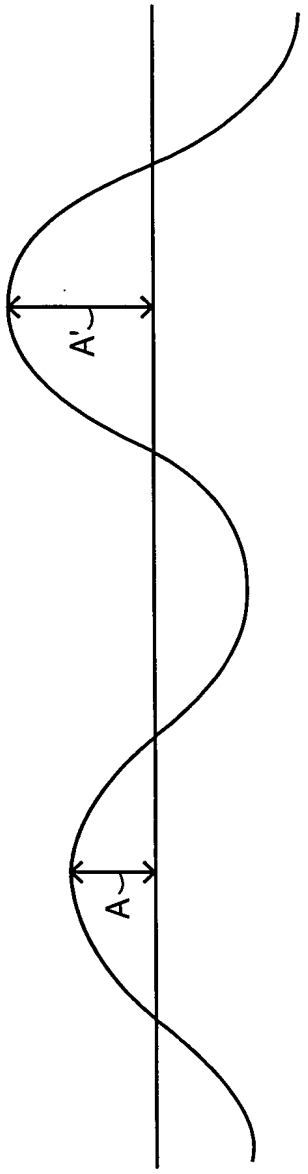


Fig. 7D

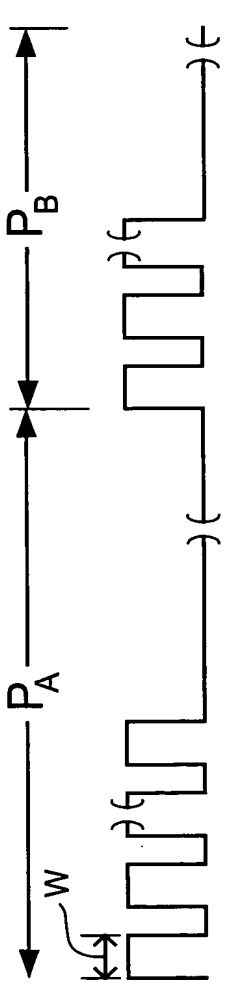


Fig. 8A

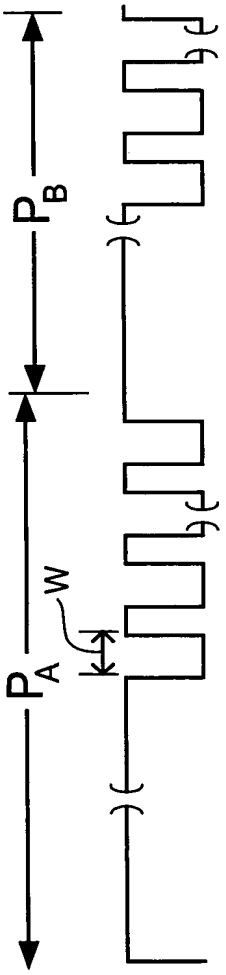


Fig. 8B

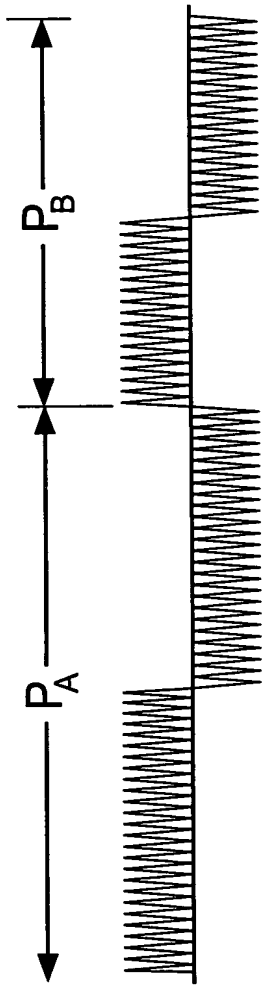


Fig. 8C

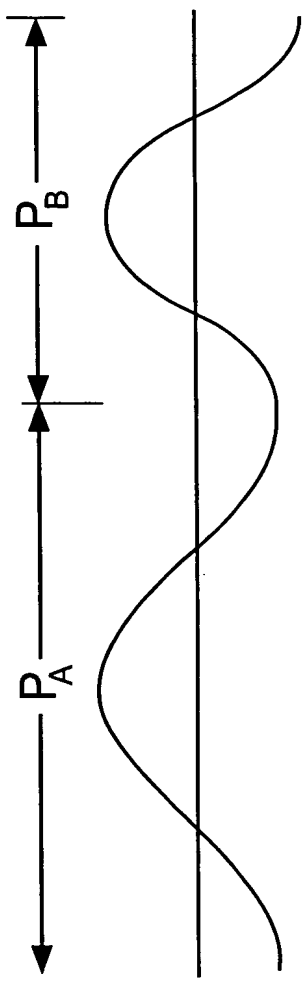


Fig. 8D

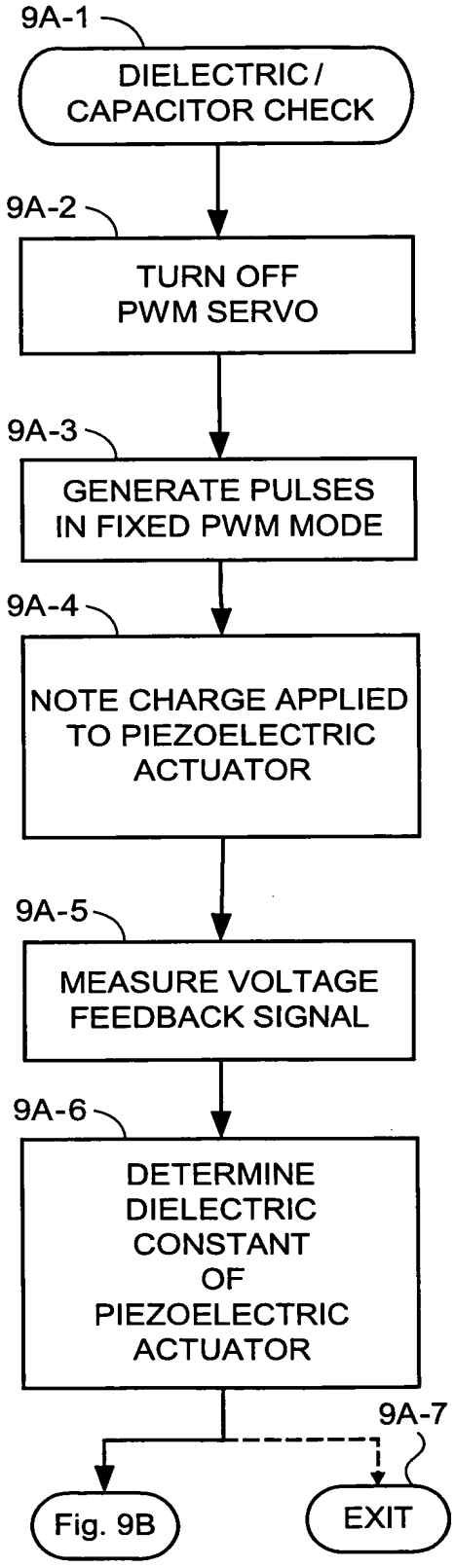

9A-1
DIELECTRIC / CAPACITOR CHECK
9A-2
TURN OFF PWM SERVO
9A-3
GENERATE PULSES IN FIXED PWM MODE
9A-4
NOTE CHARGE APPLIED TO PIEZOELECTRIC ACTUATOR
9A-5
MEASURE VOLTAGE FEEDBACK SIGNAL
9A-6
DETERMINE DIELECTRIC CONSTANT OF PIEZOELECTRIC ACTUATOR
9A-7
Fig. 9B
EXIT

Fig. 9A

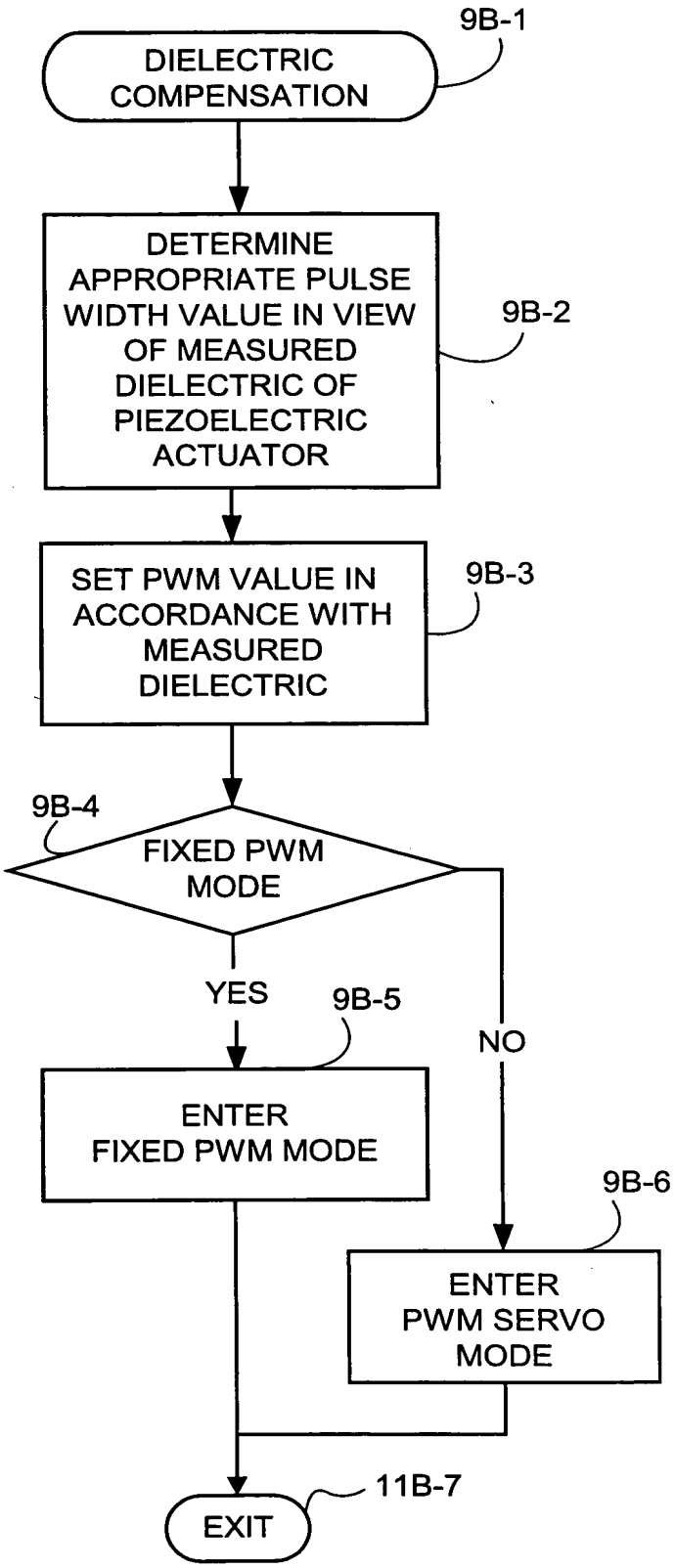

9B-1
DIELECTRIC COMPENSATION
DETERMINE APPROPRIATE PULSE WIDTH VALUE IN VIEW OF MEASURED DIELECTRIC OF PIEZOELECTRIC ACTUATOR
9B-2
SET PWM VALUE IN ACCORDANCE WITH MEASURED DIELECTRIC
9B-3
9B-4
FIXED PWM MODE
YES
9B-5
NO
ENTER FIXED PWM MODE
9B-6
ENTER PWM SERVO MODE
11B-7
EXIT

Fig. 9B

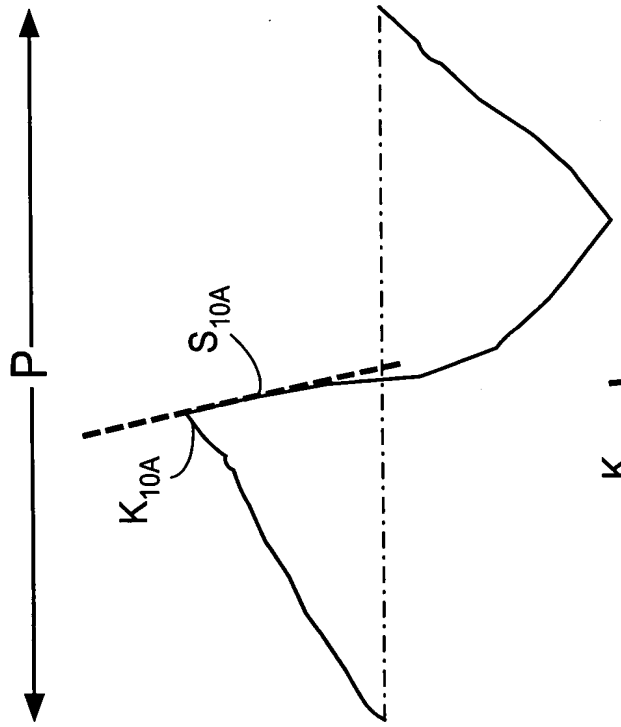


Fig. 10A

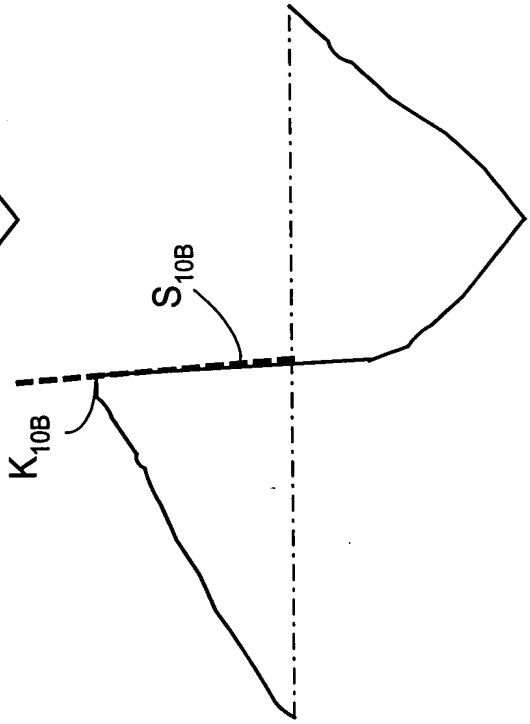


Fig. 10B

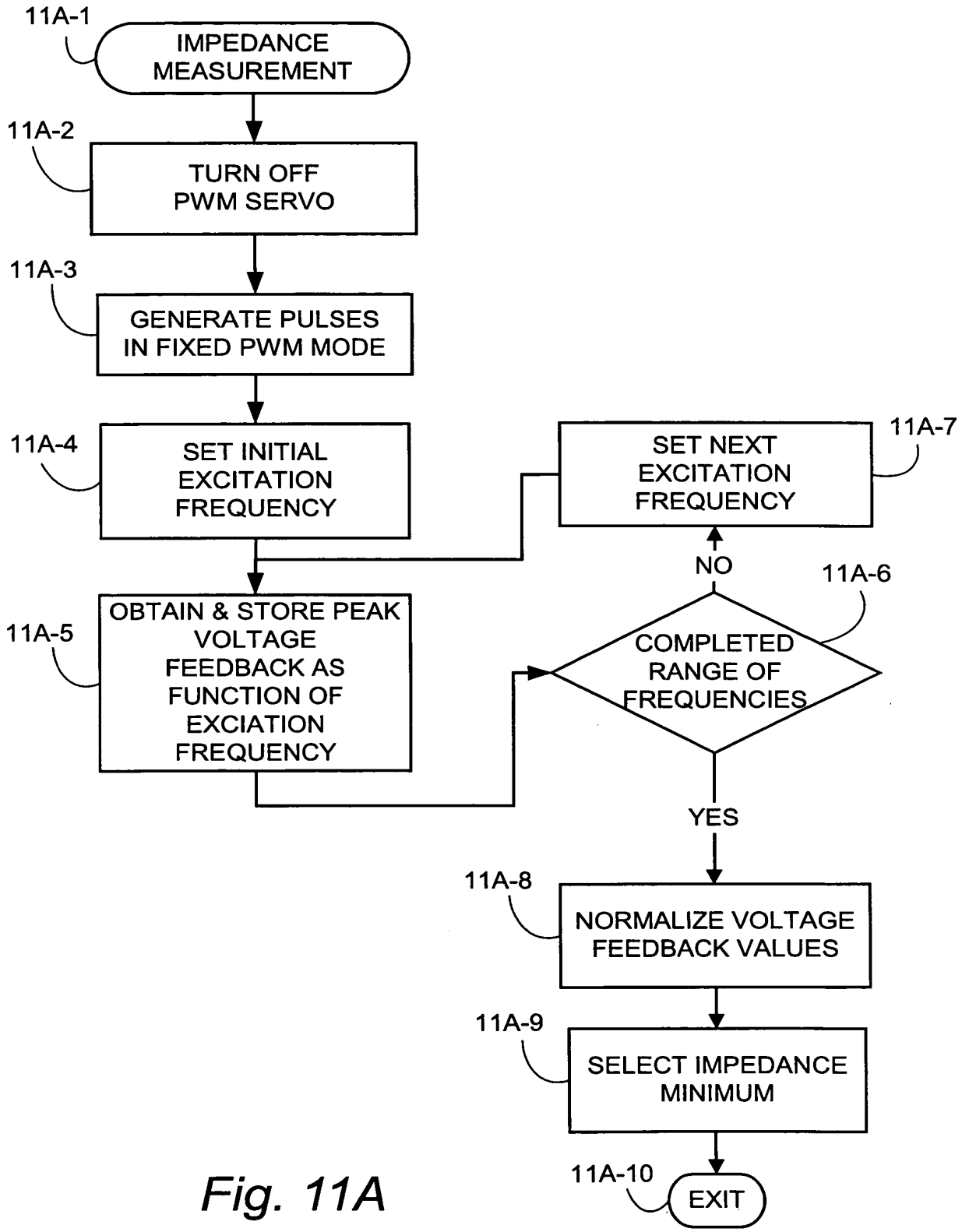

11A-1
IMPEDANCE MEASUREMENT
11A-2
TURN OFF PWM SERVO
11A-3
GENERATE PULSES IN FIXED PWM MODE
11A-4
SET INITIAL EXCITATION FREQUENCY
11A-5
OBTAIN & STORE PEAK VOLTAGE FEEDBACK AS FUNCTION OF EXCIATION FREQUENCY
11A-6
COMPLETED RANGE OF FREQUENCIES
NO
11A-7
SET NEXT EXCITATION FREQUENCY
YES
11A-8
NORMALIZE VOLTAGE FEEDBACK VALUES
11A-9
SELECT IMPEDANCE MINIMUM
11A-10
EXIT

Fig. 11A

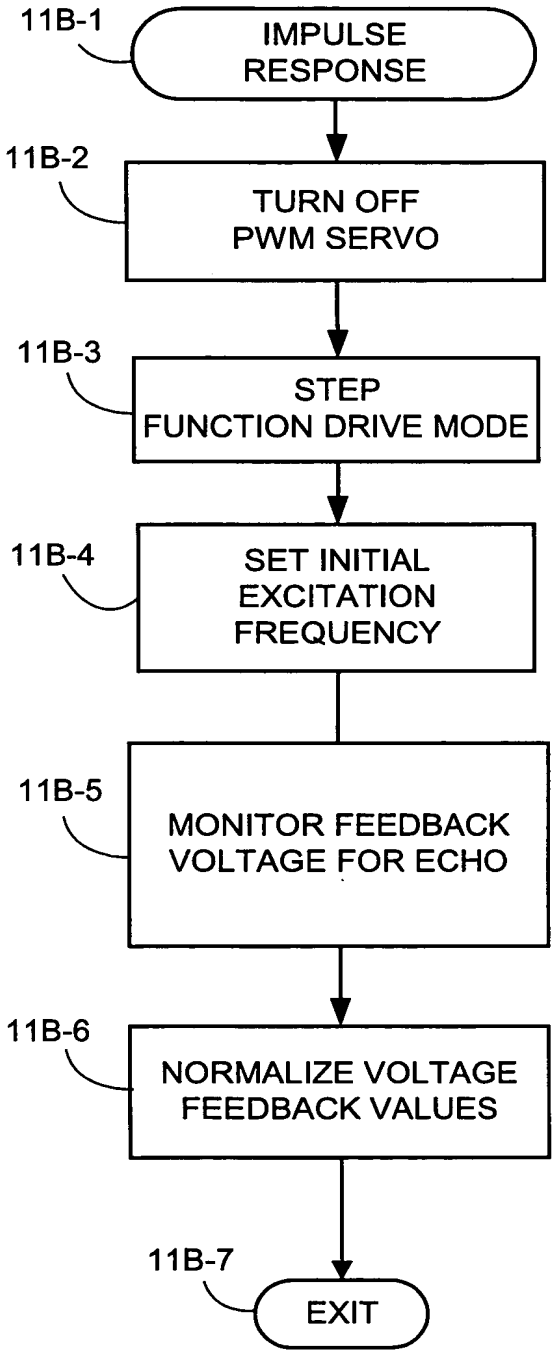

11B-1
IMPULSE RESPONSE
11B-2
TURN OFF PWM SERVO
11B-3
STEP FUNCTION DRIVE MODE
11B-4
SET INITIAL EXCITATION FREQUENCY
11B-5
MONITOR FEEDBACK VOLTAGE FOR ECHO
11B-6
NORMALIZE VOLTAGE FEEDBACK VALUES
11B-7
EXIT

Fig. 11B

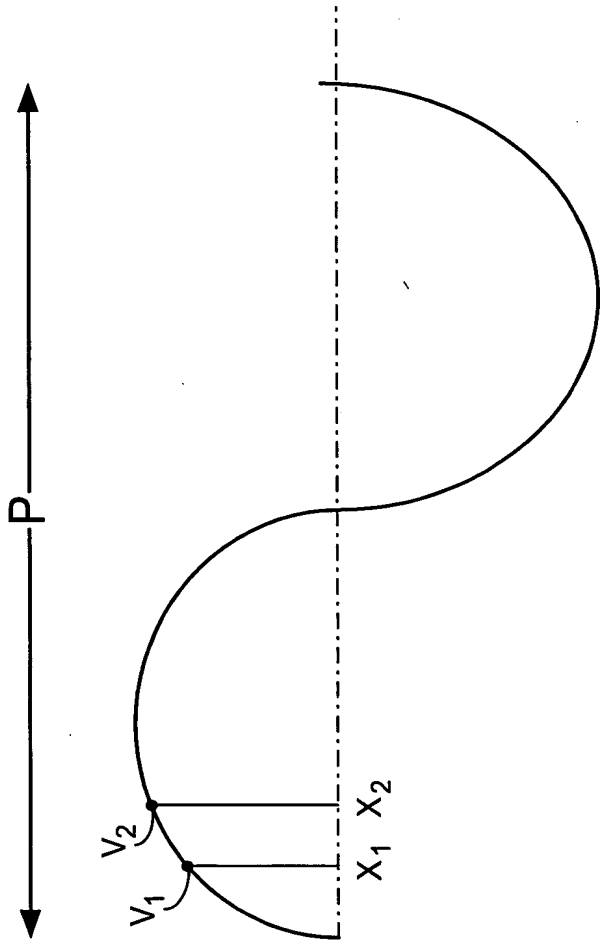
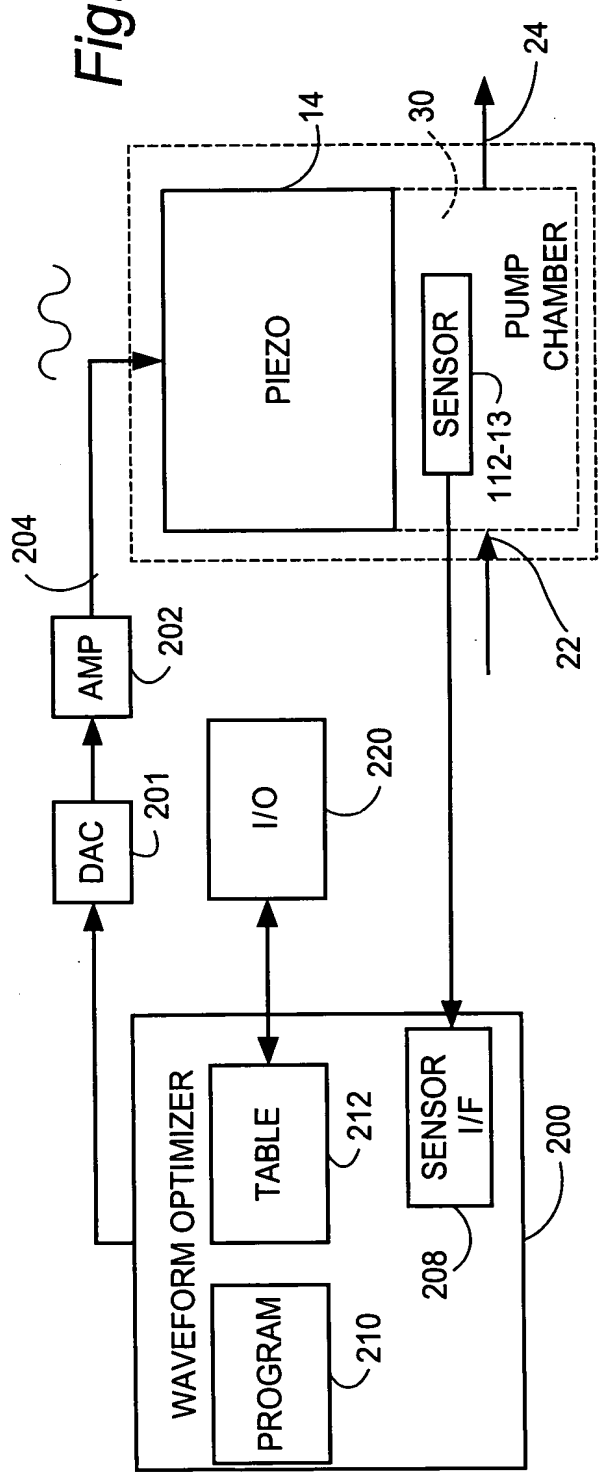


Fig. 12

Fig. 13


WAVEFORM OPTIMIZER
PROGRAM
210
TABLE
212
SENSOR I/F
208
200
DAC
201
I/O
220
AMP
202
204
PIEZO
14
30
SENSOR
112-13
PUMP CHAMBER
24
22

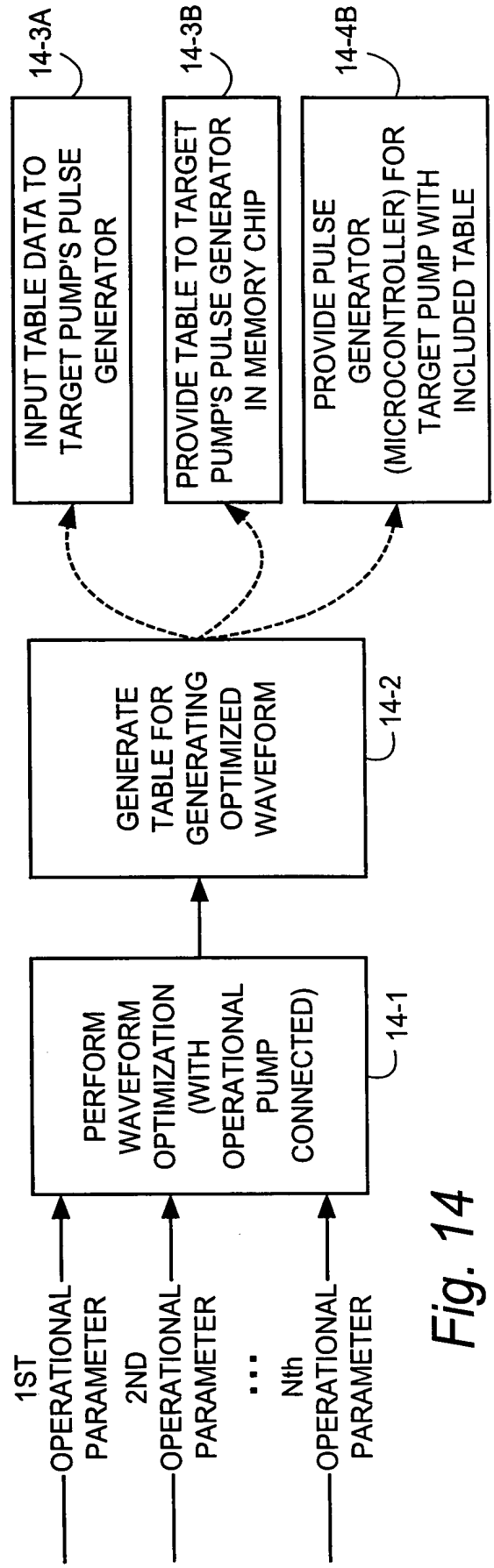

1ST OPERATIONAL PARAMETER
2ND OPERATIONAL PARAMETER
...
Nth OPERATIONAL PARAMETER
PERFORM WAVEFORM OPTIMIZATION (WITH OPERATIONAL PUMP CONNECTED)
14-1
GENERATE TABLE FOR GENERATING OPTIMIZED WAVEFORM
14-2
INPUT TABLE DATA TO TARGET PUMP'S PULSE GENERATOR
14-3A
PROVIDE TABLE TO TARGET PUMP'S PULSE GENERATOR IN MEMORY CHIP
14-3B
PROVIDE PULSE GENERATOR (MICROCONTROLLER) FOR TARGET PUMP WITH INCLUDED TABLE
14-4B

Fig. 14

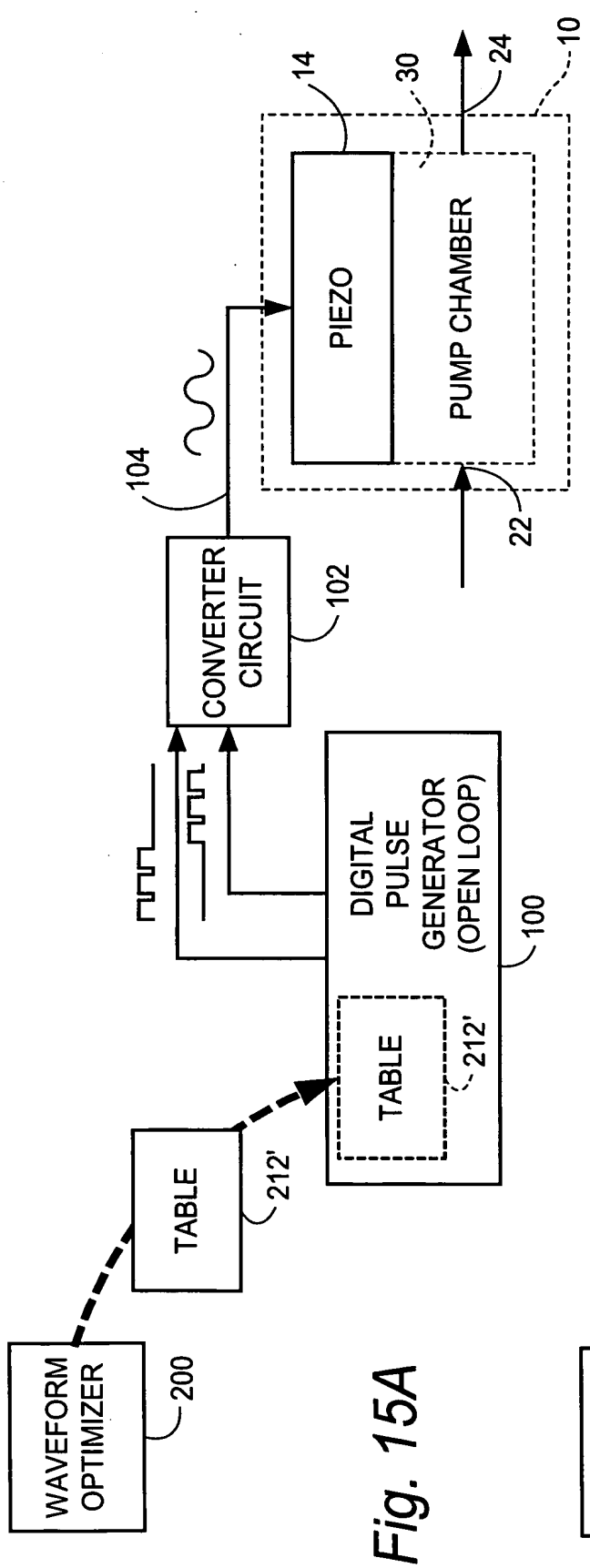


Fig. 15A

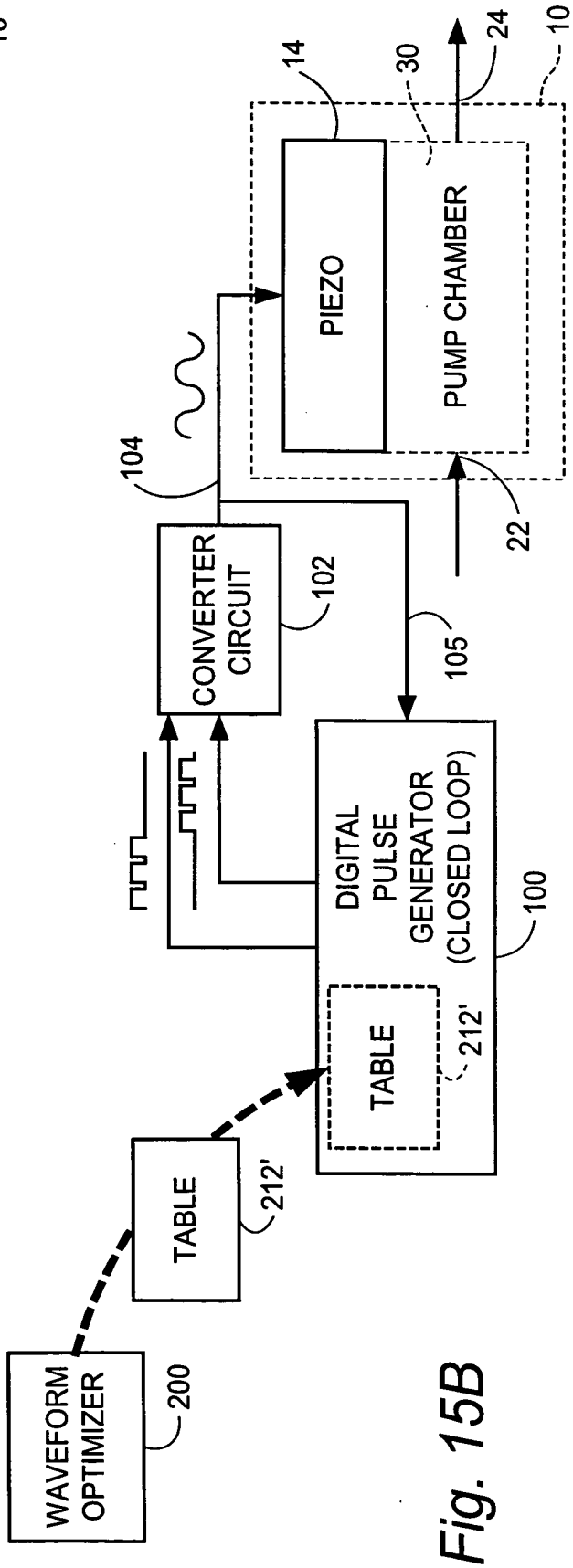


Fig. 15B

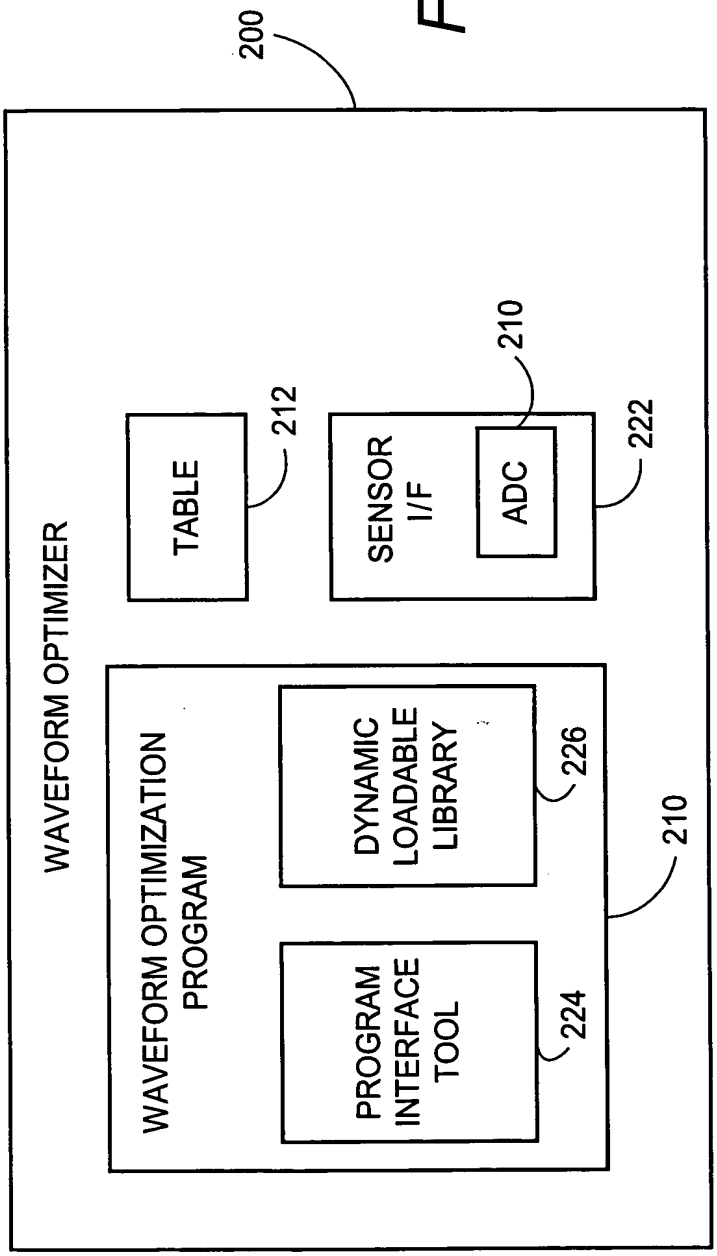

200
WAVEFORM OPTIMIZER
TABLE
212
SENSOR I/F
210
ADC
222
WAVEFORM OPTIMIZATION PROGRAM
DYNAMIC LOADABLE LIBRARY
226
PROGRAM INTERFACE TOOL
224
210

Fig. 16

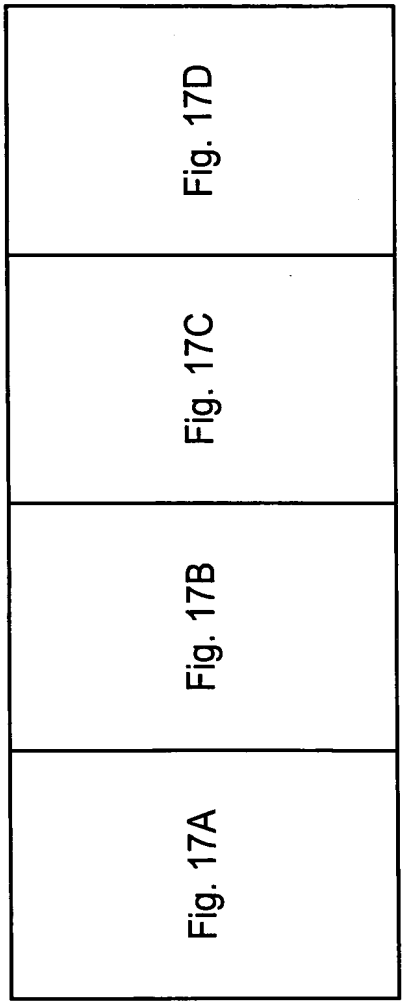


Fig. 17A
Fig. 17B
Fig. 17C
Fig. 17D

Fig. 17

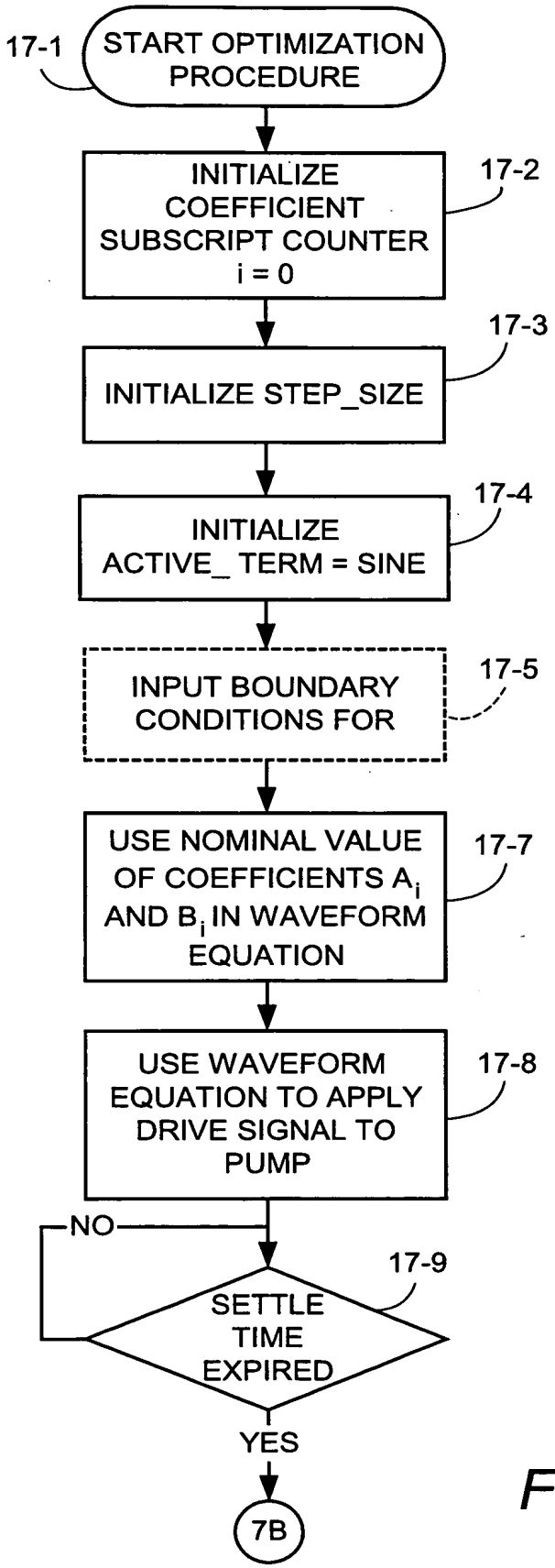

17-1
START OPTIMIZATION PROCEDURE
INITIALIZE COEFFICIENT SUBSCRIPT COUNTER i = 0
17-2
INITIALIZE STEP_SIZE
17-3
INITIALIZE ACTIVE_ TERM = SINE
17-4
INPUT BOUNDARY CONDITIONS FOR
17-5
USE NOMINAL VALUE OF COEFFICIENTS A_i AND B_i IN WAVEFORM EQUATION
17-7
USE WAVEFORM EQUATION TO APPLY DRIVE SIGNAL TO PUMP
17-8
NO
SETTLE TIME EXPIRED
17-9
YES
7B

Fig. 17A

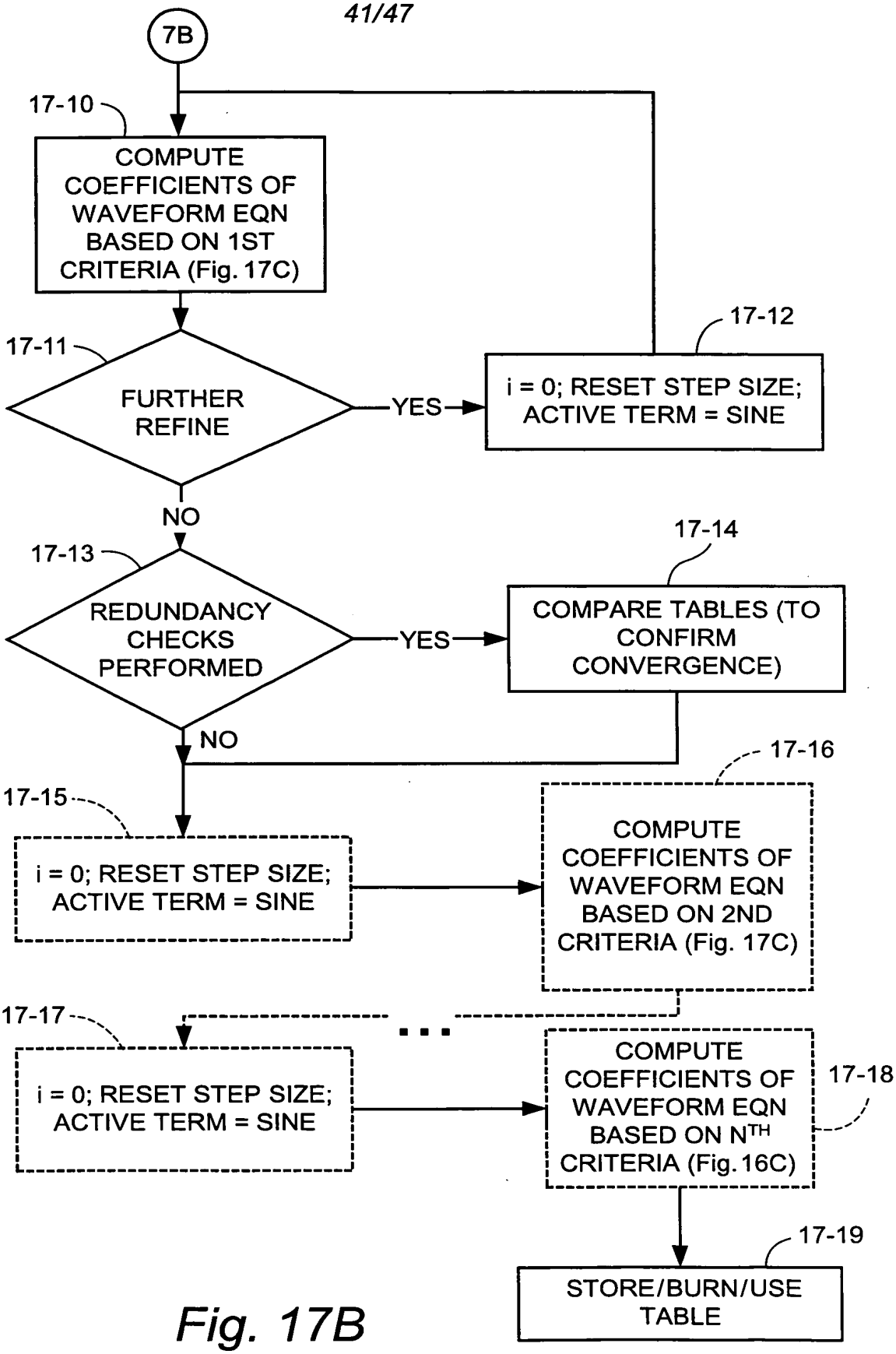
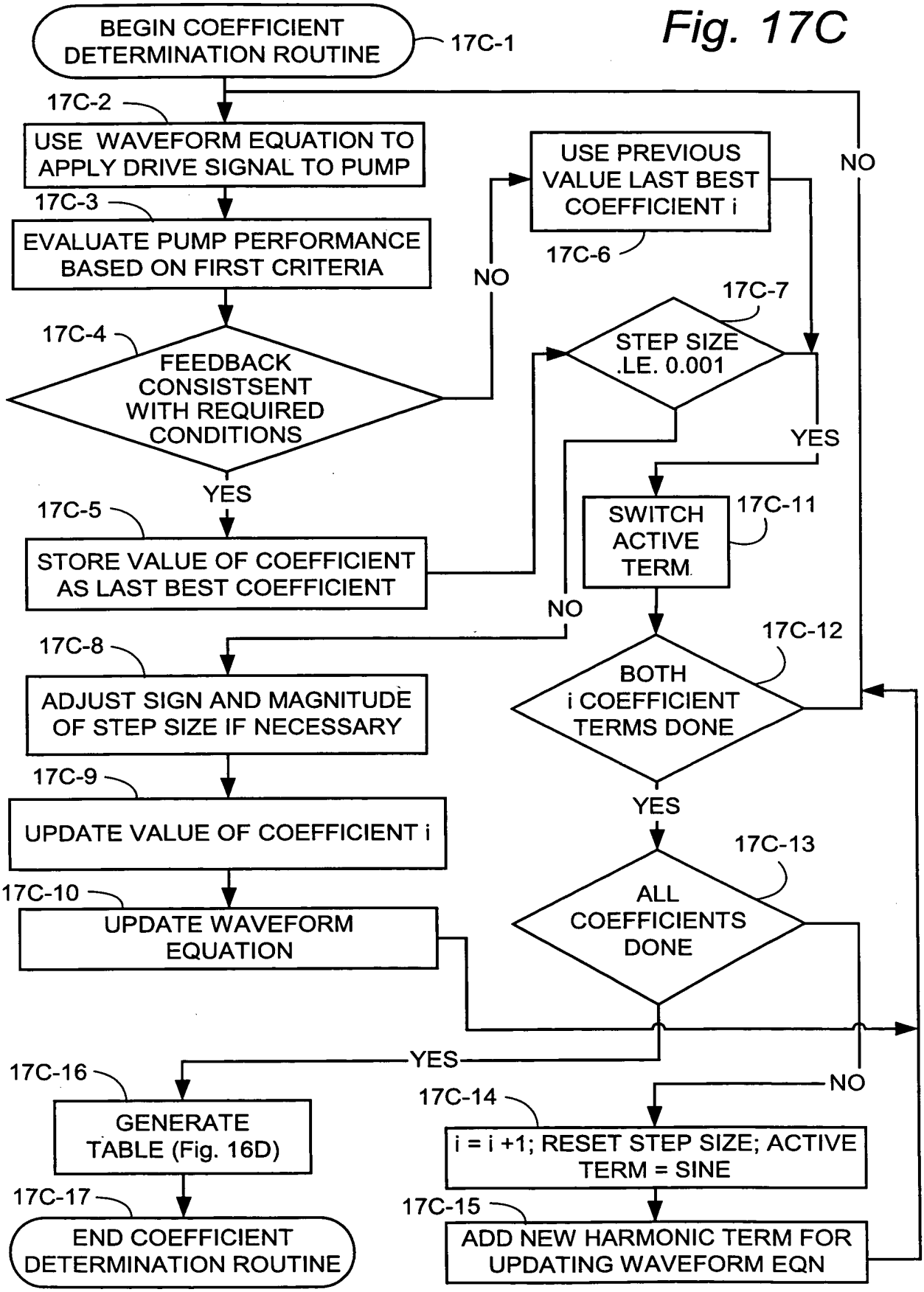

7B
17-10
COMPUTE COEFFICIENTS OF WAVEFORM EQN BASED ON 1ST CRITERIA (Fig. 17C)
17-11
FURTHER REFINE
YES
17-12
i = 0; RESET STEP SIZE; ACTIVE TERM = SINE
NO
17-13
REDUNDANCY CHECKS PERFORMED
YES
17-14
COMPARE TABLES (TO CONFIRM CONVERGENCE)
NO
17-15
i = 0; RESET STEP SIZE; ACTIVE TERM = SINE
17-16
COMPUTE COEFFICIENTS OF WAVEFORM EQN BASED ON 2ND CRITERIA (Fig. 17C)
17-17
i = 0; RESET STEP SIZE; ACTIVE TERM = SINE
COMPUTE COEFFICIENTS OF WAVEFORM EQN BASED ON N^TH CRITERIA (Fig. 16C)
17-18
17-19
STORE/BURN/USE TABLE

Fig. 17B

Fig. 17C


BEGIN COEFFICIENT DETERMINATION ROUTINE
17C-1
17C-2
USE WAVEFORM EQUATION TO APPLY DRIVE SIGNAL TO PUMP
17C-3
EVALUATE PUMP PERFORMANCE BASED ON FIRST CRITERIA
17C-4
FEEDBACK CONSISTSENT WITH REQUIRED CONDITIONS
NO
YES
17C-5
STORE VALUE OF COEFFICIENT AS LAST BEST COEFFICIENT
USE PREVIOUS VALUE LAST BEST COEFFICIENT i
17C-6
NO
17C-7
STEP SIZE .LE. 0.001
YES
NO
17C-8
ADJUST SIGN AND MAGNITUDE OF STEP SIZE IF NECESSARY
17C-9
UPDATE VALUE OF COEFFICIENT i
17C-10
UPDATE WAVEFORM EQUATION
SWITCH ACTIVE TERM
17C-11
17C-12
BOTH i COEFFICIENT TERMS DONE
YES
17C-13
ALL COEFFICIENTS DONE
YES
NO
17C-16
GENERATE TABLE (Fig. 16D)
17C-17
END COEFFICIENT DETERMINATION ROUTINE
17C-14
i = i +1; RESET STEP SIZE; ACTIVE TERM = SINE
17C-15
ADD NEW HARMONIC TERM FOR UPDATING WAVEFORM EQN

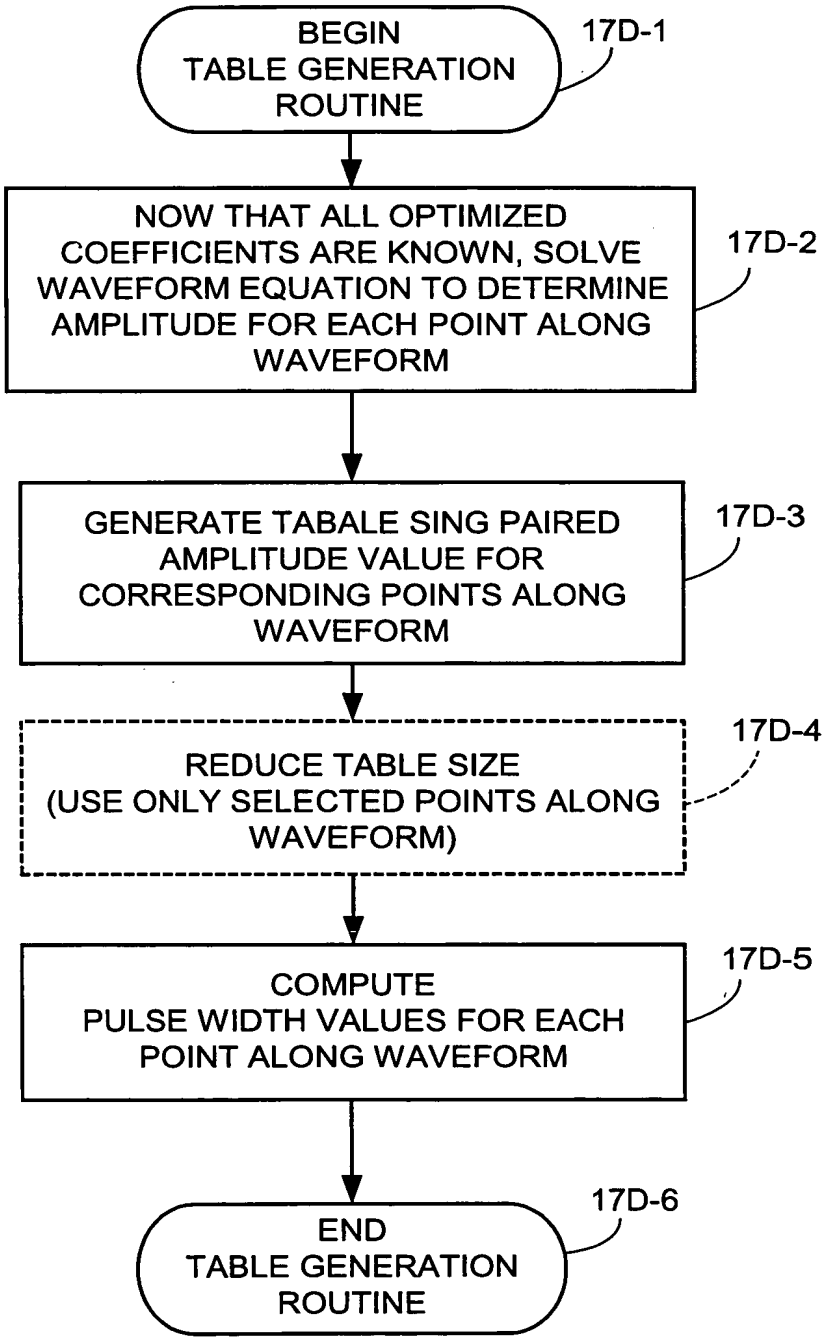

BEGIN
TABLE GENERATION
ROUTINE
17D-1
NOW THAT ALL OPTIMIZED
COEFFICIENTS ARE KNOWN, SOLVE
WAVEFORM EQUATION TO DETERMINE
AMPLITUDE FOR EACH POINT ALONG
WAVEFORM
17D-2
GENERATE TABALE SING PAIRED
AMPLITUDE VALUE FOR
CORRESPONDING POINTS ALONG
WAVEFORM
17D-3
REDUCE TABLE SIZE
(USE ONLY SELECTED POINTS ALONG
WAVEFORM)
17D-4
COMPUTE
PULSE WIDTH VALUES FOR EACH
POINT ALONG WAVEFORM
17D-5
END
TABLE GENERATION
ROUTINE
17D-6

Fig. 17D

Fig. 18A

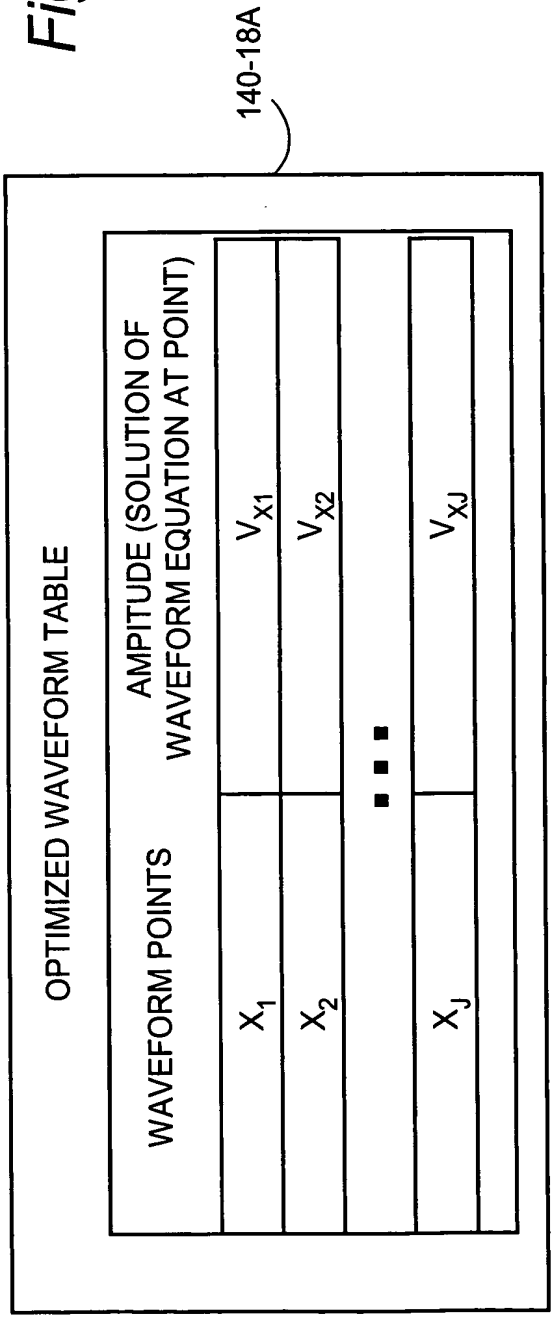
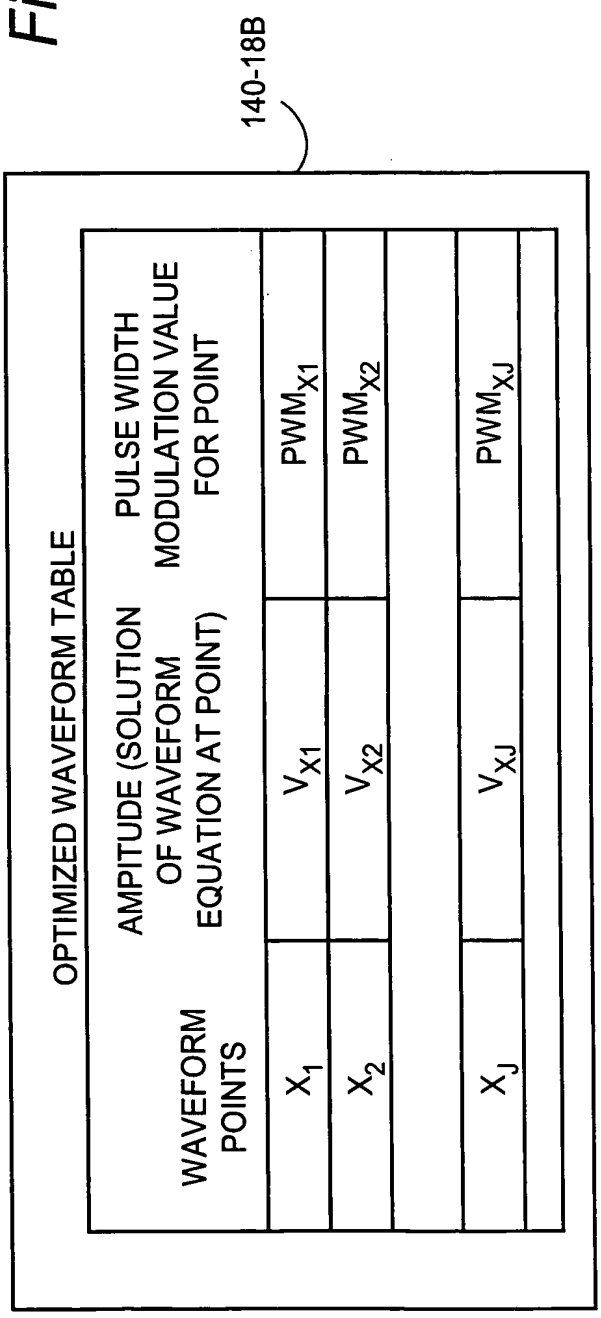


Fig. 18B



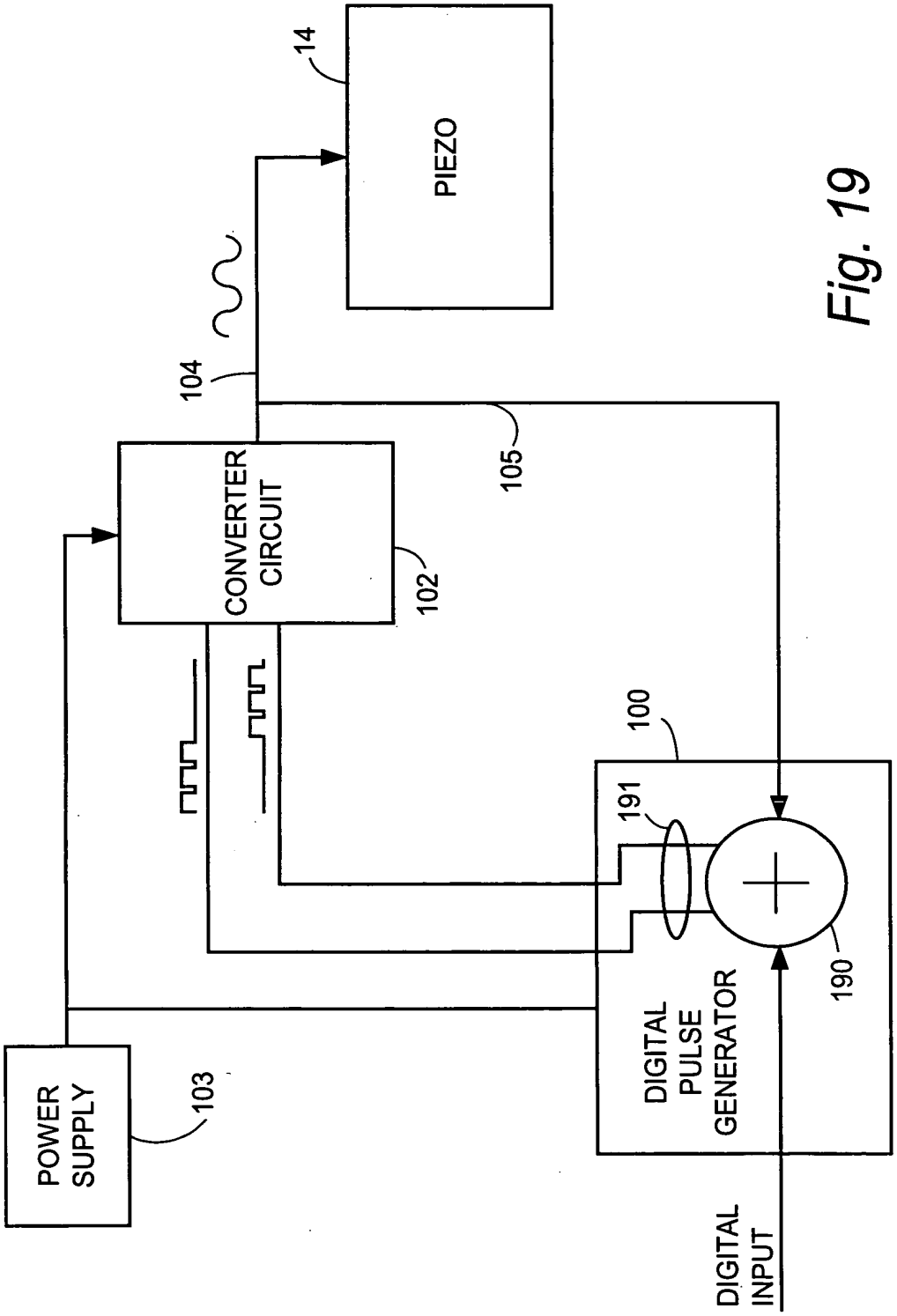

PIEZO
14
104
105
CONVERTER CIRCUIT
102
100
191
190
DIGITAL PULSE GENERATOR
POWER SUPPLY
103
DIGITAL INPUT

Fig. 19

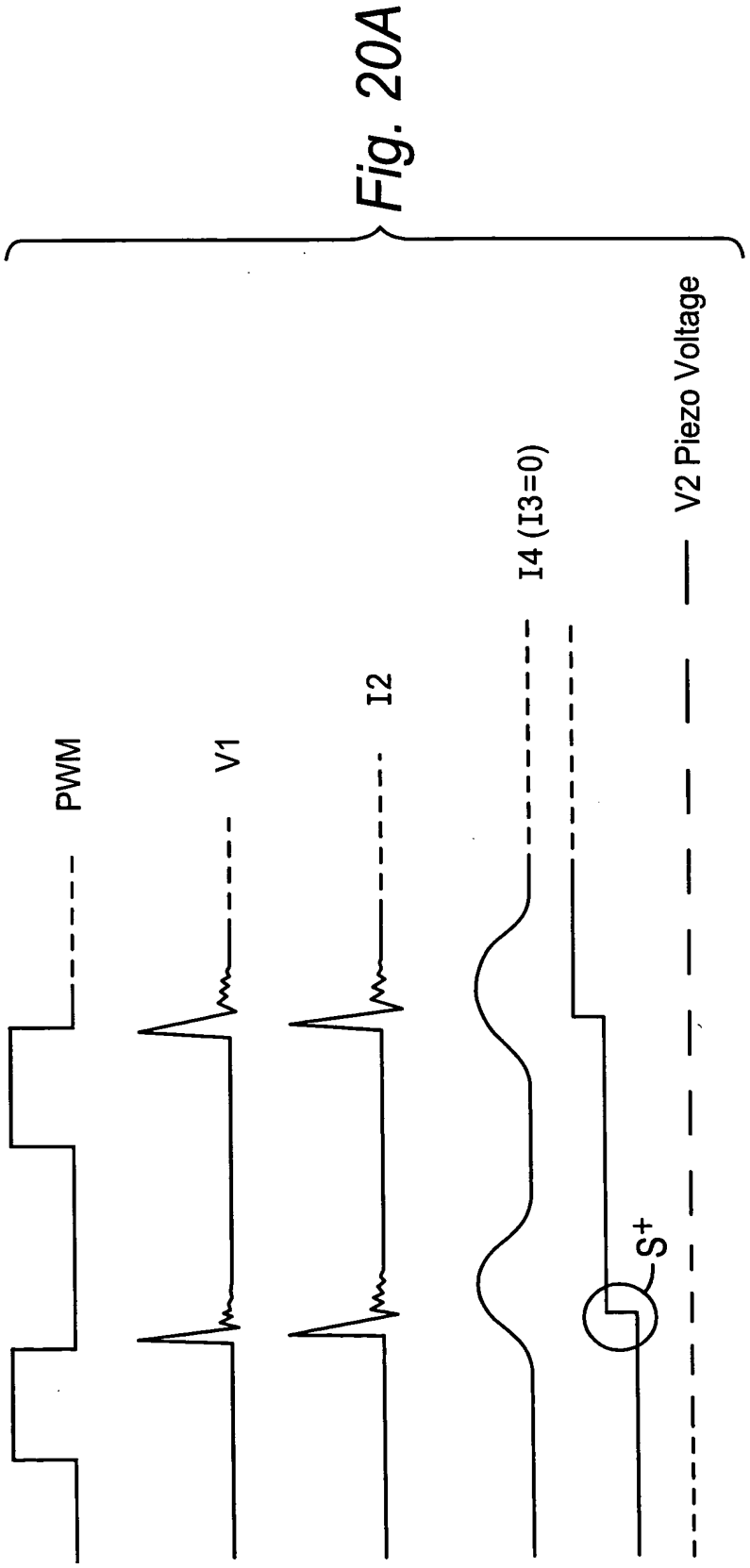


Fig. 20A

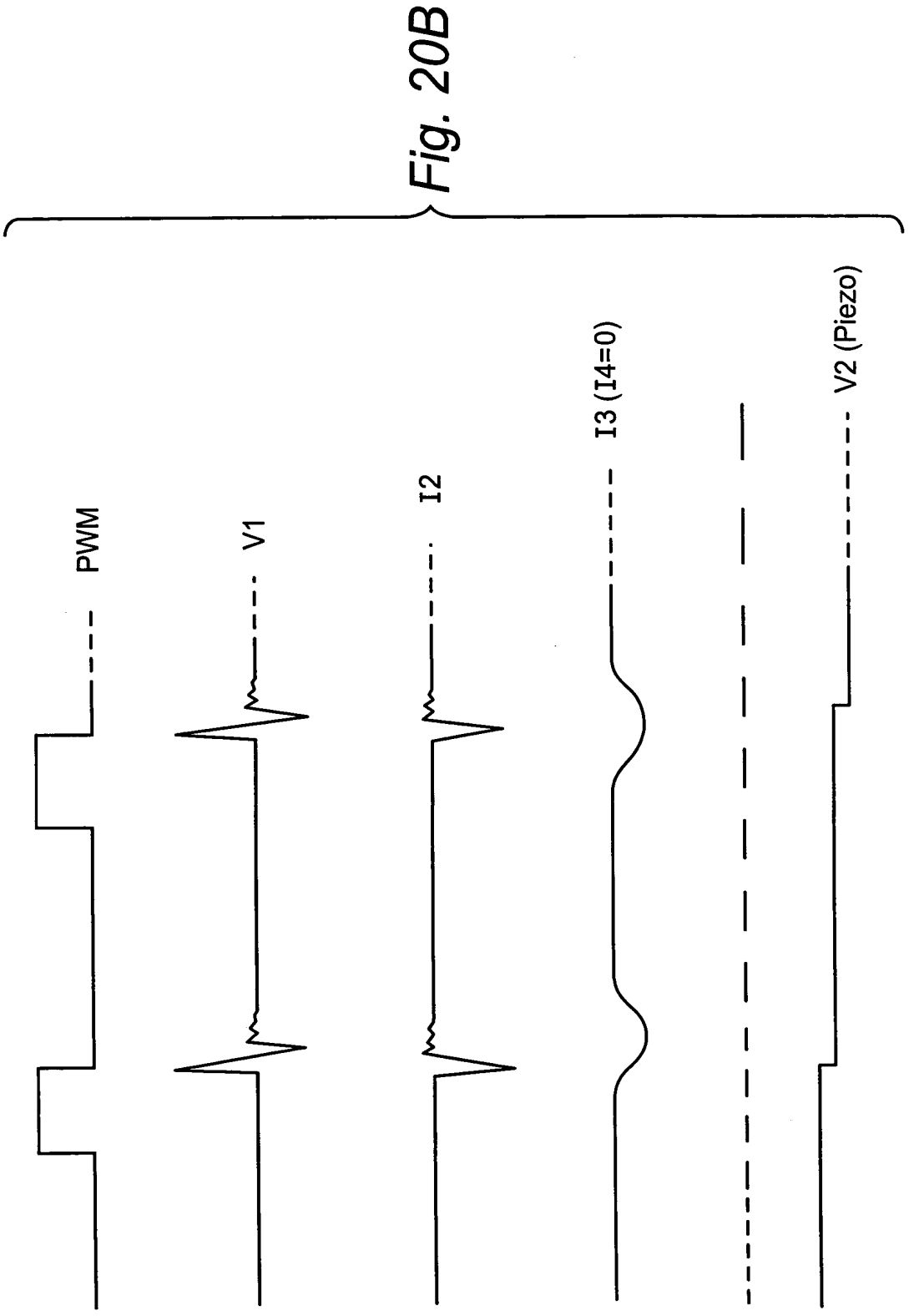


Fig. 20B